

NASA SP-35
PART 6

SPACE FLIGHT HANDBOOKS VOLUME III

PLANETARY FLIGHT
HANDBOOK

Part 6-Mars Stopover Missions
Using Venus Swingbys

General Discussion, Contour Charts
And Related Graphical Information

Prepared under contract
for NASA by
Douglas Aircraft Company



Scientific and Technical Information Division
OFFICE OF TECHNOLOGY UTILIZATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.
1968

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 75 cents

FOREWORD

This volume of the NASA Planetary Flight Handbook contains trajectory data to aid the mission analyst in the planning of stopover missions to Mars that employ the Venus swingby mode. Compared to other mission modes, the Venus swingbys yield substantial reductions in propulsive velocity and Earth entry speed requirements when employed as part of a round trip stopover mission. Conversely, the swingbys are at best, of marginal utility for one-way missions. Consequently, this Handbook has been tailored expressly for use in the planning of round trip missions. The relevant charts, graphs, and tabular data are presented for the totality of such missions, i.e., in terms of total round trip mission duration and stopover time at Mars. Recognizing, however, that within the context of round trip missions the single-leg data can be of importance in certain phases of the mission analyses, all such data has been preserved on a master magnetic tape. Copies of this tape will be made available to interested organizations.

This latest addition to the NASA SP-35 series of documents was prepared under the direction of the study manager, J. L. Horsewood, by the Missile and Space Systems Division of the Douglas Aircraft Company under contract NAS 2-4175. In addition to the efforts of the study manager, the contributions of B. A. Glassman, G. P. Bonham, and G. P. Uphoff are gratefully acknowledged. In addition, credit should be given to S. M. Norman of the NASA/OART Mission Analysis Division for her part in verifying the trajectory data. Because of their efforts, this volume should prove to be a source of comprehensive and reliable data pertaining to the Venus swingby mode. Yet it is also recognized that its preparation would not have been possible were it not for the many researchers who throughout the past several years have contributed so much to the basic understanding of these missions.

It is not the purpose of this Handbook to compare the Venus swingby mode of Mars round trips with the alternate mission modes. It remains for the mission analysts, of today, and the flight program managers, of tomorrow, to determine the most suitable means for carrying out manned exploration of Mars. It is sufficient to state here that the conviction of many who are actively engaged in the analysis of manned planetary missions is that the Venus swingby mode is a promising means by which round trip stopover missions to Mars can be carried out.

Jerry Deerwester
NASA/OART Mission Analysis Division
August 1967

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*Available upon request to the Technical Information Division, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California 94035.

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Section 1

GENERAL DISCUSSION

This handbook contains a series of charts and tables of trajectory data for round-trip Mars stopover missions using Venus swingbys. The trajectory data are presented for the more favorable missions that are available in the 1975-1999 time period. The data in this handbook are restricted to those missions which combine a direct leg and a ballistic Venus swingby leg; that is, missions which employ Venus swingbys on both the outbound and inbound legs are not included. Round trip missions with stopover times at Mars of zero, 30, and 60 days are presented. Also, as an aid to the analyst, the minimum mission velocity requirements and associated Earth entry speeds for each opportunity are presented as a function of mission duration for both propulsive braking and aerodynamic braking at Mars.

Background Information

The first indications of the potential advantages of employing Venus swingbys for Mars missions were provided through the independent efforts of Sohn¹ and Hollister². These and the subsequent works of Deerwester³, Gillespie and Ross⁴, and Deerwester and D'Haem⁵ gave quantitative evidence that the Venus swingby mode offers substantial savings in propulsion and entry speed requirements over the more familiar direct mode. Also of great importance was the conclusion that Mars missions employing the Venus swingby occur periodically and may be predicted far into the future.

The periodicity of the Venus swingby missions is due to the fact that relative configurations among the planets Earth, Mars, and Venus repeat almost exactly every 2338 days (~6.4 years). This time interval constitutes a syzygetic period during which Venus passes through inferior conjunction four times, Mars passes through opposition three times and Venus and Mars pass through their mutual alignment seven times.

Since short flight time, low energy trajectories between any two of these planets are characterized by departure prior to and arrival after the date of an alignment, the knowledge of when all of the alignments occur is important in predicting the availability of Venus swingby missions.

Since relative configurations among the three planets repeat every 6.4 years, one would expect that similar swingby missions would also repeat every 6.4 years, at least in a qualitative sense. Furthermore, because of the many alignment configurations that occur during this period, it is reasonable to expect that there may exist more than one class of swingby trajectories within each syzygistic period. Gillespie and Ross⁴ approached this possibility by considering whether, for return flights from Mars to Earth, there existed favorable (i.e., low energy) trajectories from Mars to Venus and from Venus to Earth with common dates at Venus. They reasoned that there could be no more than seven classes of swingby trajectories within a syzygistic period because in that time period only seven Mars-Venus alignments occur, and this type of alignment recurs most frequently. Commencing with a particular Mars-Venus alignment date, chosen for convenience as a reference because it is near the date that both planets are in conjunction with Earth, consecutive alignments were numbered from one to seven, covering a complete syzygistic period. This numbering system is illustrated later in Table 2-4.

Upon studying the Mars-to-Venus trajectories associated with each of the seven alignments, it was possible to immediately eliminate from contention Category^{*} 2, 4, and 6 trajectories because there existed no favorable Venus-to-Earth trajectories which departed Venus on or near the arrival dates of favorable trajectories from Mars. Furthermore, subsequent studies showed that although Category 1 and 7 trajectories are theoretically possible, they are not competitive with the direct Mars-to-Earth trajectories either in terms of energy requirements or flight time. This leaves, then, Category 3 and 5 inbound Venus swingby missions that are of interest in each syzygistic period. Finally, because of the near mirror image relationship between inbound and outbound

^{*}The terminology "Type" rather than "Category" was employed by Gillespie and Ross. To prevent confusion with the more common terminology in which a trajectory Type 1 or 2 denotes transfer angles less than or greater than 180 degrees, respectively, the term Category is employed here.

trajectories, it is possible to number the Mars-Venus alignments from one to seven in reverse chronological order, commencing from the same reference alignment, such that the conclusions drawn above for inbound swingby trajectories will apply also to outbound swingby trajectories. Hence, within one syzygetic period four swingby opportunities (i.e., Category 3 and Category 5, both inbound and outbound) are of interest and call for detailed examination.

Between the years 1975 and 1999, inclusive, nearly four full syzygetic periods take place. Thus, there are a total of 16 mission opportunities in the 25 year period. Information pertaining to each of the 16 opportunities is presented in Table 1-1. In subsequent discussions, the year of the Earth-Mars opposition, rather than Earth departure year for example, is used to distinguish between the various opportunities. Each opportunity is directly related to a specific opposition through the direct leg of the round trip mission which

TABLE 1-1
MISSION OPPORTUNITIES

Earth-Mars Opposition		Mars-Venus Alignment (Julian Date)	Category Number	Mission Profile
Year	(Julian Date)			
1975	244 2762	244 3016	3	Inbound Swingby
1978	3530	3367	5	Outbound Swingby
1978	3530	3685	5	Inbound Swingby
1980	4295	4034	3	Outbound Swingby
1982	5060	5366	3	Inbound Swingby
1984	5832	5693	5	Outbound Swingby
1984	5832	6032	5	Inbound Swingby
1986	6622	6362	3	Outbound Swingby
1988	7433	7701	3	Inbound Swingby
1990	8223	8028	5	Outbound Swingby
1990	8223	8370	5	Inbound Swingby
1993	8995	244 8694	3	Outbound Swingby
1995	244 9761	245 0027	3	Inbound Swingby
1997	245 0525	0378	5	Outbound Swingby
1997	0525	0694	5	Inbound Swingby
1999	245 1293	245 1047	3	Outbound Swingby

is in progress when the opposition takes place. Note in Table 1-1 that the Category 5 outbound and inbound opportunities within the same syzygistic period utilize a common opposition, although the Mars-Venus alignment dates are different.

Handbook Content

This handbook is comprised of six sections. The explanatory text, of which this discussion is a part, is contained in Section 1. The explanatory text describes the technical approach employed in generating the data and provides brief descriptions of the mathematical model assumed for the study. In Section 2, a table of the planetary constants that were employed in the trajectory calculations is presented. Also included are auxiliary charts and tables, including a planetary ephemeris, which will assist the mission analyst in studying the swingby opportunities. The trajectory data are presented in graphical form in Section 3. The graphical presentation consists of a set of three charts for each mission opportunity. The first is termed a contour chart which displays constant contours of hyperbolic excess speeds, Venus passage date and passage distance on a grid of date at Earth and date at Mars. The second chart shows the minimum total mission velocity requirements as a function of mission duration for both propulsive braking and aerodynamic braking at Mars. The corresponding Earth entry velocities are shown in the third chart, also as a function of mission duration. Sections 1, 2, and 3 are bound together to facilitate their use independently of the tabular data.

The detailed trajectory data for the round-trip Mars missions are tabulated in Sections 4, 5, and 6 for stopover times of zero, 30, and 60 days, respectively. The three sections are bound separately as Supplements A, B, and C and can be obtained from the Technical Information Division, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California 94035.

Technical Approach

This handbook is specifically designed for studies of round-trip Mars stop-over missions. The outbound and inbound trajectories were generated separately and then matched to yield round-trip missions with specified mission durations and stopover times. For each mission opportunity, the swingby

trajectory data were evaluated first. The Venus swingby date and either the launch or arrival date of the swingby leg were used as the primary independent parameters. The variation of arrival date with swingby date for given launch date is nearly linear in some opportunities while the launch date-swingby date variation is more nearly linear in other opportunities. To expedite the interpolation procedures, the date that is least linear with swingby date was chosen as the independent parameter*. The Venus swingby date was incremented a specific amount (two days and five days for Category 5 and 3 swingbys, respectively), holding the launch (arrival) date constant. An interpolation procedure was used to obtain the trajectories corresponding to specific values of the arrival (launch) date. This interpolation procedure was also employed to isolate trajectories that lie on the constant hyperbolic excess speed and passage distance contours. The incrementing of Venus swingby date was automatically terminated at specified bounds of either the swingby date or the arrival (launch) date. After completing the sweep of the swingby date, the launch (arrival) date was incremented (ten days) and the procedure repeated.

Table 1-2 lists the ranges of dates which were searched to obtain both the

TABLE 1-2
RANGES OF DATES INVESTIGATED

Note: Dates are Julian minus 244 0000

Mission Opportunity	Direct Leg		Swingby Leg		
	Depart	Arrive	Depart	Swingby	Arrive
1975 Inbound	2500-2730	2650-2950	2700-2930	3010-3070	3100-3260
1978 Outbound	3460-3640	3620-3880	3140-3220	3280-3360	3460-3580
1978 Inbound	3230-3480	3490-3620	3460-3620	3680-3810	3800-4000
1980 Outbound	4100-4390	4300-4630	3800-3920	3990-4030	4100-4330
1982 Inbound	4800-5030	5100-5300	5150-5300	5360-5410	5450-5600
1984 Outbound	5750-5970	5830-6200	5470-5580	5560-5650	5750-5910
1984 Inbound	5600-5830	5780-6020	5840-6020	6000-6200	6120-6350
1986 Outbound	6410-6690	6600-6900	6110-6230	6300-6340	6410-6630
1988 Inbound	7180-7440	7420-7630	7480-7630	7710-7760	7800-7960
1990 Outbound	7850-8260	8180-8500	7770-7870	7930-8010	7980-8200
1990 Inbound	7950-8150	8200-8340	8170-8320	8380-8500	8460-8600
1993 Outbound	8760-9010	9000-9250	8470-8590	8650-8710	8760-8950
1995 Inbound	9500-9700	9740-9950	9800-9950	10000-10080	10120-10320
1997 Outbound	10370-10660	10550-10800	10060-10300	10230-10360	10370-10600
1997 Inbound	10220-10450	10510-10650	10470-10630	10710-10800	10780-11110
1999 Outbound	11100-11360	11300-11550	10790-10910	10980-11030	11100-11300

*Experience has shown that this date is the departure date of the swingby leg for Category 3 outbound swingbys and Category 5 inbound swingbys. Arrival date is employed for the remaining opportunities.

direct and the swingby-leg trajectory data for each of the mission opportunities. The trajectory data for the complete round-trip missions were obtained by matching the appropriate outbound and inbound legs.

Computer Programs and Models

The program used to obtain the trajectory data is based on patched conic theory and requires as inputs the Julian date of departure from the launch planet (or the date of arrival at the target planet) and the date of passage of the swingby planet. These input dates are used in conjunction with a set of mean elements to locate the launch and swingby planets (and thereby the terminals of the trajectory) on the dates of interest. An internal ephemeris routine treats all planetary orbits as eccentric, mutually inclined ellipses which are fixed in space. The elements of the planetary orbits were extracted from Reference 6 and are presented subsequently in Section 2.

The elements of any conic trajectory, given the two terminal radius vectors and the transfer time, are evaluated by means of an iterative solution to Kepler's Equation. This solution is terminated when the desired transfer time is achieved within a tolerance of 0.01 percent of the desired transfer time. This technique is employed to evaluate each transfer leg of the interplanetary mission.

The computation of swingby trajectories is based on the theory that the sole effect of a close planet passage is to rotate the hyperbolic excess velocity vector. The problem is one of determining that particular trajectory between the swingby and the target planets for which the hyperbolic excess speed at departure is the same as that at arrival on the trajectory from the launch planet. The definition of the post-encounter trajectory possessing the desired characteristic is achieved through the use of an automated iterative search procedure. This procedure employs an internally generated guess of the post-encounter trajectory transfer time as an input into the trajectory routine described in the preceding paragraph. The transfer time is then perturbed to find the sensitivity of hyperbolic excess speed at departure with respect to transfer time. This sensitivity is used in conjunction with the difference

in the desired and the achieved departure hyperbolic excess speeds to define a closer estimate of the transfer time. This iterative procedure is repeated until the departure speed matches the arrival speed within 3 m/sec.

The numerical techniques employed in performing the iteration described above are based on the shape of the curve of departure hyperbolic excess speed as a function of flight time for a typical transfer from Venus to the target planet. The general shape of this curve is shown in Figure 1-1 where V_∞ represents the speed at Venus, t_f is the flight time from Venus to the target planet, and ϕ is the transfer angle between Venus and the target planet. The highly sensitive region in the center is characteristic and occurs at the transition from Type 1 ($\phi < 180^\circ$) to Type 2 ($\phi > 180^\circ$) trajectories. The desired value of departure speed (which is the speed of arrival at Venus) may be any value along the vertical scale; three representative cases are shown by the horizontal dashed lines denoted a, b, and c. It is seen that from zero to four solutions to the problem may be available. When four solutions are available there exist two each for Type 1 and Type 2 trajectories. For each type, the shorter flight time solution is termed Class 1 and the longer flight time solution is termed Class 2. Each of the four solutions represents different trip times, different swingby passage distances, and, in general,

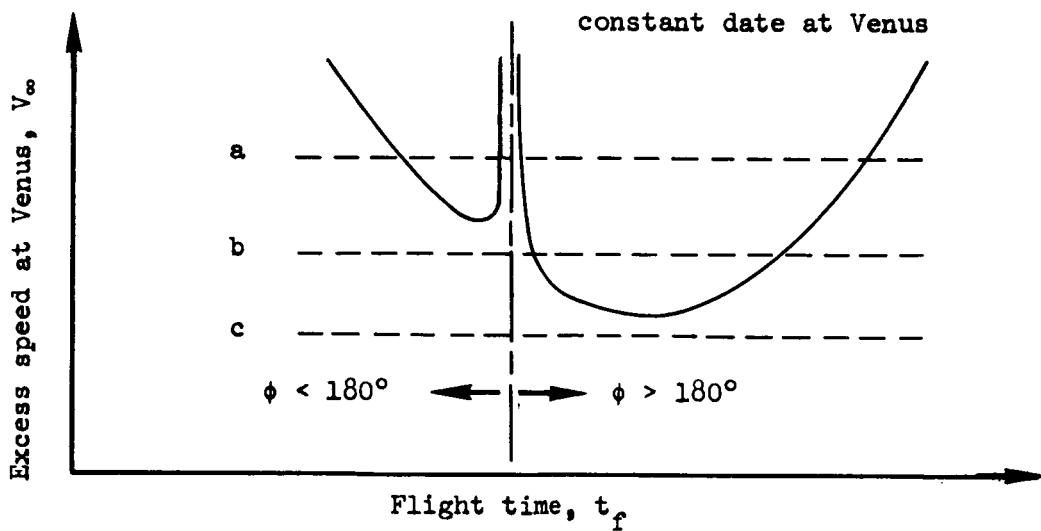


Fig. 1-1 Characteristic Behavior of Hyperbolic Excess Speed

completely different trajectories. Usually, no more than one or two of the solutions yield passage distances above the surface of the swingby planet. Each of the potential solutions was investigated individually by input option of the trajectory types and classes of interest. A preliminary investigation was performed first to determine the date ranges associated with each type and class. For those ranges that overlapped the regions of interest as stated in Table 1-2, a detailed investigation was conducted of the corresponding type and class.

Magnetic Tape of Trajectory Data

It is anticipated that there will exist frequent need to utilize the trajectory data in this handbook as inputs to computer programs for systems and missions studies. To facilitate such studies, the one-way trajectory data that were generated in the preparation of the handbook were stored on a master magnetic tape which will be made available on request*. The data on the tape include both direct and swingby trajectories, and are provided in ten day increments in both departure and arrival dates over the date ranges given in Table 1-2. The swingby trajectories included are limited to those for which the Venus passage distance is greater than 0.95 Venus radii. The trajectory data on the tape include all parameters provided in the tabular output with the exception of the incremental velocities for departing from or braking into circular parking orbits and the atmospheric entry velocities. These parameters were excluded because they are dependent on the orbit altitudes assumed, but may easily be computed for any desired altitude from the data provided.

A copy of the tape may be obtained by submitting a request to the Director, Mission Analysis Division, Office of Advanced Research and Technology, National Aeronautics and Space Administration, Moffett Field, California 94035. A standard magnetic tape, 2400 feet in length and 1/2 inch in width, must accompany the request.

*A detailed description of the organization of the data on the tape is contained in the Appendix.

Section 2

PLANETARY CONSTANTS AND RELATED INFORMATION

Contained in this section are many of the planetary orbital and physical constants used in the calculation of the interplanetary trajectories. Also, other information that will be useful to the trajectory analyst is included.

In Table 2-1 are presented the constants used in the calculations for this handbook. For the most part, these constants are taken directly from References 6 and 7. The exceptions to this are the gravitational parameters for the Sun, Venus, Earth and Mars which are taken from Reference 8; the planetary radii (equatorial) which are taken from Reference 9; and the parking orbit and atmospheric entry altitudes which were specified by the NASA, OART Mission Analysis Division at the initiation of this study.

The incremental velocity required to depart from or brake into low altitude circular orbits is shown in Figure 2-1 as a function of hyperbolic excess speed for both Earth and Mars. Also shown as a function of the hyperbolic excess speed is the atmospheric entry velocity for the two planets. The altitudes employed in these calculations were those selected for the study and which are listed in Table 2-1. Actually, the velocities are quite insensitive to these altitudes; therefore, the results are valid for a wide range of circular orbit altitudes.

The bend angle, K, through which the hyperbolic asymptote of the Venus passage trajectory is deflected at encounter is shown in Figure 2-2 as a function of hyperbolic excess speed at Venus for selected passage distances ranging from one to five Venus radii. The passage distance is measured from the center of Venus to the perifocal point on the passage hyperbola. The data in Figure 2-2 were obtained from the equation

$$K = 2 \arcsin \left(1 + \frac{r_p v_\infty^2}{\mu_\oplus} \right)^{-1}$$

where r_p is the passage distance in km, v_∞ is the hyperbolic excess speed in km/sec, and μ_p is the gravitational parameter of Venus in km^3/sec^2 .

In Tables 2-2, 2-3, and 2-4 are presented listings of the dates of Mars opposition, Venus inferior conjunction, and Mars-Venus alignment, respectively, for the time period 1975-1999. These phenomena are defined as the time when the heliocentric longitudes of the two planets involved are equal. The tables include the Julian dates, the corresponding calendar dates, and the heliocentric longitudes at which the phenomena occur. In addition, the swingby trajectory category number, discussed in Section 1, that is associated with each Mars-Venus alignment is shown in Table 2-4 for both inbound and outbound swingbys. The data in these tables were generated using the orbital elements listed in Table 2-1.

Table 2-5 contains a tabulation of the positions and related information of the planets Earth, Venus and Mars for every 10 days through the time period 1975-1999. For each of the planets the following information is provided: (1) heliocentric longitude, (2) heliocentric latitude, (3) heliocentric distance, (4) right ascension of Sun, and (5) declination of Sun. In addition, the communication distances from Earth are provided for Venus and Mars. The angles are expressed in degrees, and distances are given in AU. The data presented in this table were generated using the fixed ellipse models of the planetary orbits as described by the elements given in Table 2-1. While these values are not the most accurate ones obtainable, they are sufficiently accurate for preliminary design purposes and they were chosen to make this handbook consistent with Reference 6. An estimate of the error introduced by the fixed ellipse model was obtained by a comparison of ephemeris and trajectory data for the year 1999 (the errors are largest for the later years) with equivalent data obtained using accurate, time varying mean elements. The comparison indicated discrepancies in the heliocentric longitude of about 0.1 - 0.2 degrees for each of the planets Venus, Earth, and Mars. The general effect of these differences on the energy requirements were to change the hyperbolic excess speeds in the fourth significant digit. Because only three significant digits in excess speed are printed in the tabular output, the discrepancies in energy requirements will generally not be noticeable in the handbook.

TABLE 2-1
PLANETARY CONSTANTS

	VENUS	EARTH	MARS
Semi-major Axis (AU)*	0.723 332	1.000 000	1.523 691
Eccentricity	0.006 793	0.016 726	0.093 368
Inclination to Ecliptic (Deg)	3.394 23	0.0	1.849 91
Mean Longitude of Node (Deg)	76.319 72	0.0	49.249 03
Mean Longitude of Perihelion (Deg)	131.008 31	102.252 53	335.322 69
Mean Longitude at Epoch** (Deg)	174.294 31	100.158 15	258.767 29
Mean Motion (Deg/Day)	1.602 131	0.985 609	0.524 033
Siderial Period (Days)	224.701	365.256	686.98
Synodic Period (Days)	583.92	-----	779.94
Mean Orbital Speed (EMOS)***	1.175 8	1.0	0.810 1
Gravitational Parameter [†] (10 ⁵ Km ³ /Sec ²)	3.248 534	3.986 032	0.429 778
Planetary Radius (Km)	6100	6378	3415
Inclination of Equator to Orbit Plane (Deg)	0.0	23.450	23.984
Position of Vernal Equinox (Deg)	0.0	-102.27	-67.01
Parking Orbit Altitude (Km)	-----	485	500
Atmospheric Entry Altitude (Km)	-----	120	300

* 1 AU = 149,599,000 Km

** EPOCH: 1.5 Jan 1960 E.T. (2436935.0 Julian)

*** 1 EMOS = 29.766 Km/Sec

[†] GM_{Sun} = 1.32715445 x 10¹¹ Km³/Sec²

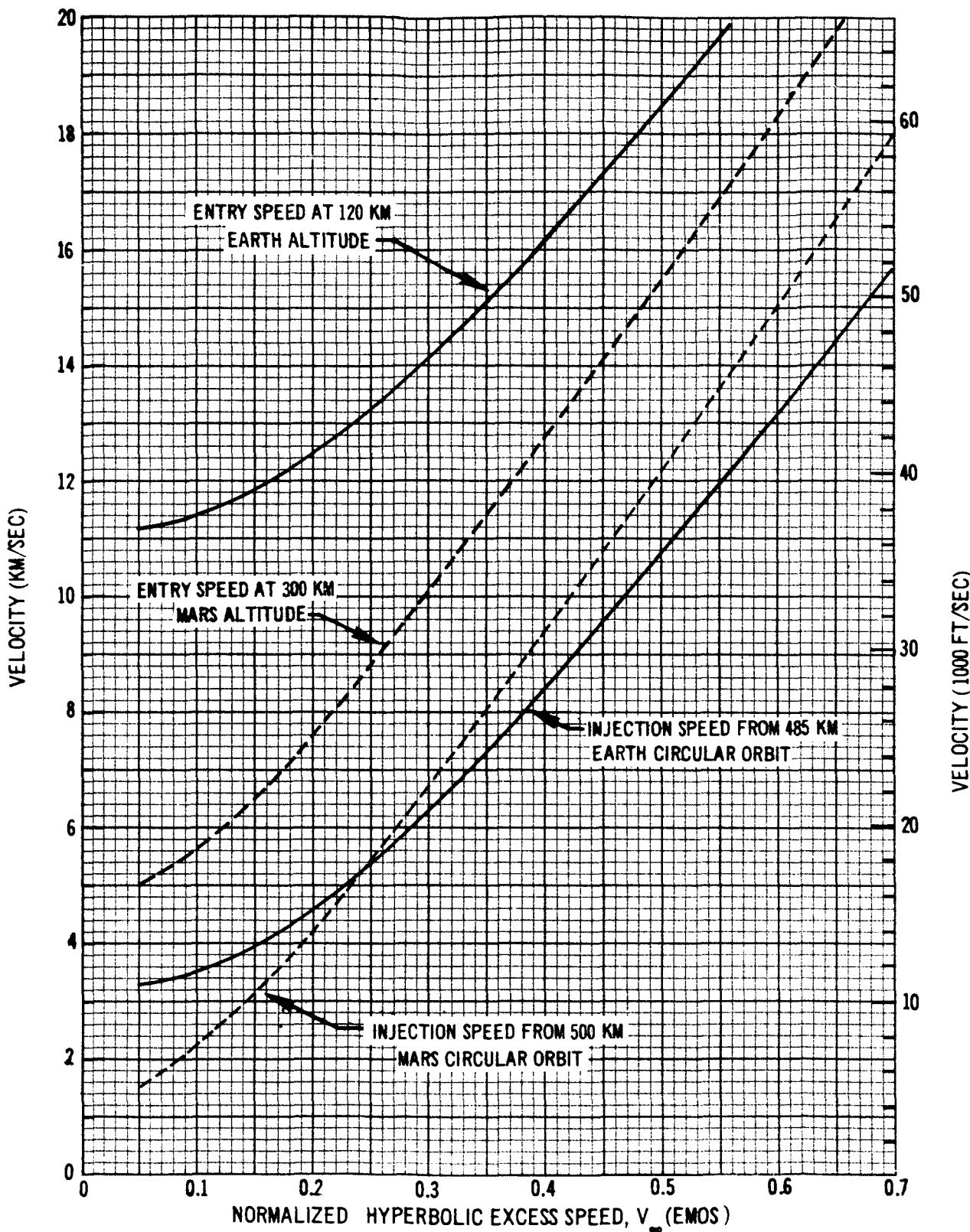


FIGURE 2-1 HYPERBOLIC EXCESS SPEED CONVERSIONS — EARTH AND MARS

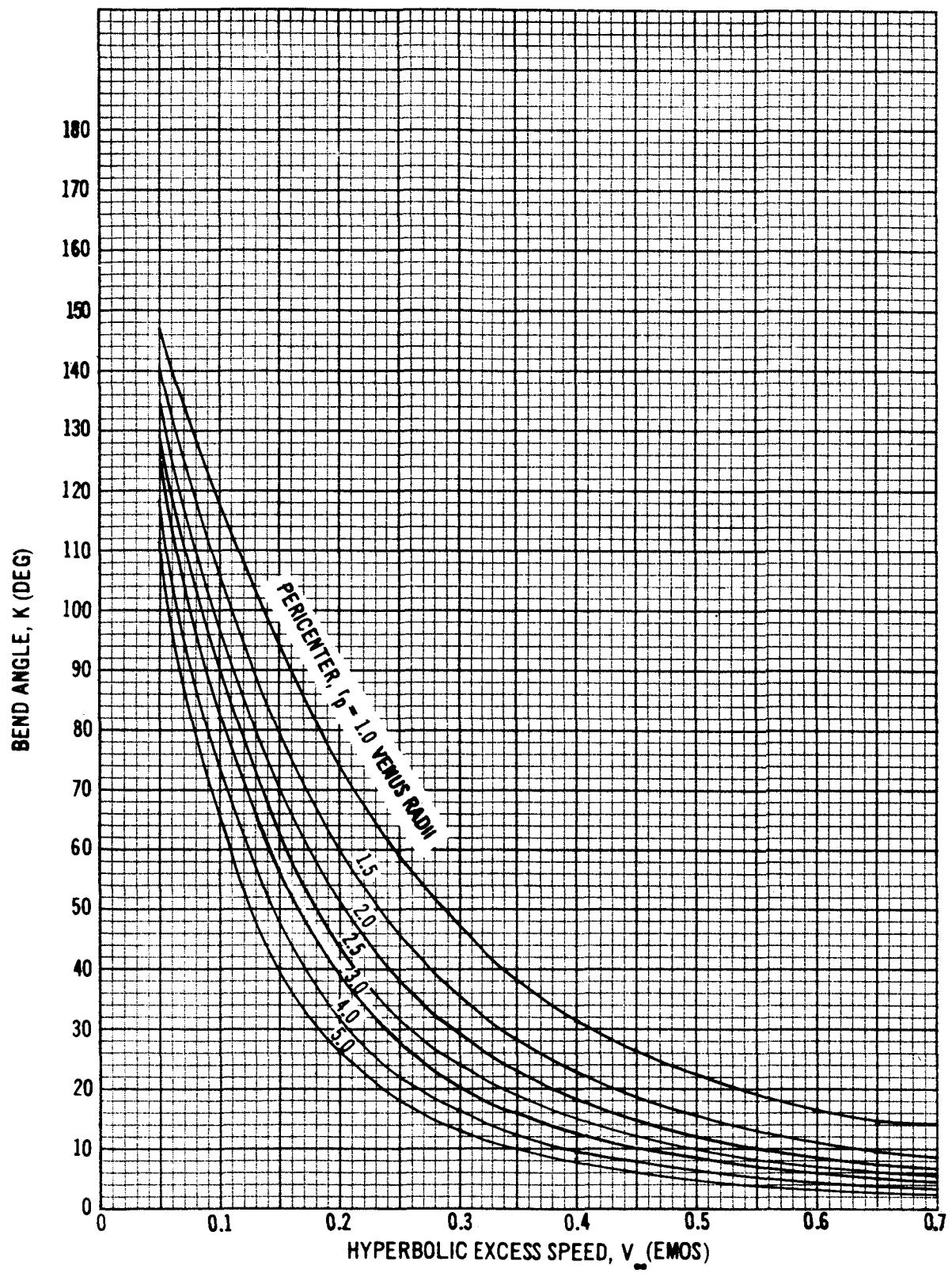


FIGURE 2-2 HYPERBOLIC ASYMPTOTE DEFLECTION ANGLE AT VENUS

TABLE 2-2
OPPOSITIONS OF MARS, 1975-1999

<u>Julian Date</u>	<u>Calendar Date</u>	<u>Heliocentric Longitude</u>
2442762.1	15.6 Dec 1975	82.75°
2443530.5	22.0 Jan 1978	121.35°
2444294.7	25.2 Feb 1980	155.48°
2445059.9	31.4 Mar 1982	190.03°
2445831.9	11.4 May 1984	230.50°
2446621.8	10.3 Jul 1986	287.37°
2447432.7	28.2 Sep 1988	4.92°
2448223.3	27.8 Nov 1990	64.90°
2448995.4	7.9 Jan 1993	107.15°
2449760.5	12.0 Feb 1995	142.35°
2450524.8	17.3 Mar 1997	176.20°
2451293.2	24.7 Apr 1999	213.51°

TABLE 2-3
INFERIOR CONJUNCTIONS OF VENUS, 1975-1999

<u>Julian Date</u>	<u>Calendar Date</u>	<u>Heliocentric Longitude</u>
2442652.0	27.5 Aug 1975	333.42°
2443239.8	6.3 Apr 1977	196.11°
2443820.4	7.9 Nov 1978	44.85°
2444405.8	15.3 Jun 1980	264.05°
2444990.9	21.4 Jan 1982	120.75°
2445571.7	25.2 Aug 1983	331.09°
2446159.4	3.9 Apr 1985	193.73°
2446739.9	5.4 Nov 1986	42.33°
2447325.5	13.0 Jun 1988	261.79°
2447910.4	18.9 Jan 1990	118.18°
2448491.3	22.8 Aug 1991	328.77°
2449079.0	1.5 Apr 1993	191.35°
2449659.5	3.0 Nov 1994	39.80°
2450245.2	10.7 Jun 1996	259.52°
2450830.0	16.5 Jan 1998	115.60°
2451411.0	20.5 Aug 1999	326.46°

TABLE 2-4
MARS-VENUS ALIGNMENTS, 1975-1999

<u>Julian Date</u>	<u>Calendar Date</u>	<u>Heliocentric Longitude</u>	<u>Inbound</u>	<u>Category</u>	<u>Outbound</u>
2442700.1	14.6 Oct 1975	49.97°	2		7
2443016.2	25.7 Aug 1976	197.90°	3		6
2443367.1	11.6 Aug 1977	38.68°	4		5
2443685.2	25.7 Jun 1978	189.71°	5		4
2444033.8	9.3 Jun 1979	26.79°	6		3
2444354.4	24.9 Apr 1980	181.71°	7		2
2444700.1	5.6 Apr 1981	14.32°	1		1
2445023.6	23.1 Feb 1982	173.84°	2		7
2445366.0	31.5 Jan 1983	1.32°	3		6
2445692.9	24.4 Dec 1983	166.08°	4		5
2446031.7	27.2 Nov 1984	347.93°	5		4
2446362.3	23.8 Oct 1985	158.37°	6		3
2446697.2	23.7 Sep 1986	334.33°	7		2
2447031.6	24.1 Aug 1987	150.68°	1		1
2447362.7	20.2 Jul 1988	320.72°	2		7
2447701.0	23.5 Jun 1989	142.97°	3		6
2448028.4	16.9 May 1990	307.33°	4		5
2448370.3	23.8 Apr 1991	135.19°	5		4
2448694.3	12.8 Mar 1992	294.34°	6		3
2449039.6	21.1 Feb 1993	127.31°	7		2
2449360.5	8.0 Jan 1994	281.87°	1		1
2449708.7	22.2 Dec 1994	119.28°	2		7
2450027.1	5.6 Nov 1995	270.00°	3		6
2450377.8	21.3 Oct 1996	111.06°	4		5
2450694.1	2.6 Sep 1997	258.73°	5		4
2451046.7	21.2 Aug 1998	102.60°	6		3
2451361.4	1.9 Jul 1999	248.05°	7		2

TABLE 2-5 (CONT.)

JULIAN DATE	EARTH					MARS					VENUS					JULIAN DATE		
	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	
4-4500.0	354.5	.0	1.00	174.9	2.2	252.6	-.7	1.49	165.6	6.3	1.96	53.7	-1.3	.72	102.6	.0	.89	4-4500.0
4-4510.0	4.2	.0	1.00	183.9	-1.7	258.0	-.9	1.48	170.6	4.2	2.01	69.8	-.4	.72	118.7	.0	.96	4-4510.0
4-4520.0	14.1	.0	1.00	193.0	-5.6	263.6	-1.0	1.47	175.7	1.9	2.04	85.9	-.6	.72	134.9	.0	1.03	4-4520.0
4-4530.0	24.0	.0	1.00	202.2	-9.3	269.3	-1.2	1.46	180.9	-4.4	2.08	102.1	1.5	.72	151.1	.0	1.10	4-4530.0
4-4540.0	33.9	.0	.99	211.7	-12.6	275.1	-1.3	1.44	186.2	-2.7	2.11	118.3	2.3	.72	167.3	.0	1.17	4-4540.0
4-4550.0	44.0	.0	.99	221.5	-16.0	280.9	-1.5	1.43	191.6	-5.1	2.14	134.5	2.9	.72	183.6	.0	1.23	4-4550.0
4-4560.0	54.0	.0	.99	231.6	-18.8	286.9	-1.6	1.42	197.1	-7.4	2.17	150.6	3.3	.72	199.8	.0	1.29	4-4560.0
4-4570.0	64.1	.0	.99	242.1	-21.0	292.9	-1.7	1.41	202.7	-9.7	2.19	167.0	3.4	.72	216.0	.0	1.34	4-4570.0
4-4580.0	74.2	.0	.99	252.9	-22.5	299.0	-1.7	1.40	208.5	-12.0	2.22	183.2	3.2	.72	232.2	.0	1.40	4-4580.0
4-4590.0	84.4	.0	.98	263.9	-23.3	305.2	-1.8	1.40	214.4	-14.1	2.24	199.4	2.8	.72	248.3	.0	1.44	4-4590.0
4-4600.0	94.6	.0	.98	275.0	-23.4	311.4	-1.8	1.39	220.6	-16.1	2.26	215.5	2.2	.72	264.4	.0	1.49	4-4600.0
4-4610.0	104.8	.0	.98	286.1	-22.6	317.7	-1.8	1.39	226.8	-18.0	2.28	231.3	1.4	.72	280.4	.0	1.53	4-4610.0
4-4620.0	115.0	.0	.98	296.9	-21.1	324.0	-1.8	1.38	233.2	-19.6	2.29	247.4	1.5	.73	296.4	.0	1.57	4-4620.0
4-4630.0	125.2	.0	.98	307.5	-19.0	330.3	-1.8	1.38	239.8	-21.0	2.31	263.3	1.4	.73	312.3	.0	1.60	4-4630.0
4-4640.0	135.3	.0	.99	317.8	-16.3	336.7	-1.8	1.38	246.5	-22.2	2.33	279.1	-1.3	.73	328.1	.0	1.63	4-4640.0
4-4650.0	145.4	.0	.99	327.7	-13.0	343.0	-1.7	1.38	253.3	-23.1	2.34	294.9	-2.1	.73	343.9	.0	1.66	4-4650.0
4-4660.0	155.5	.0	.99	337.3	-9.5	349.4	-1.6	1.38	260.2	-23.7	2.36	310.7	-2.6	.73	359.6	.0	1.68	4-4660.0
4-4670.0	165.5	.0	.99	346.7	-5.7	355.7	-1.5	1.39	267.1	-24.0	2.37	326.5	-3.2	.73	356.0	.0	1.70	4-4670.0
4-4680.0	175.5	.0	.99	355.9	-1.8	1.9	-1.4	1.39	273.9	-23.9	2.39	342.4	-3.4	.73	314.1	.0	1.71	4-4680.0
4-4690.0	185.5	.0	1.00	36.0	2.2	8.1	-1.1	1.40	280.7	-23.6	2.40	358.3	-3.3	.73	47.2	.0	1.72	4-4690.0
4-4700.0	195.3	.0	1.00	14.1	6.0	14.3	-1.1	1.41	287.4	-23.0	2.41	14.2	-3.0	.73	63.1	.0	1.73	4-4700.0
4-4710.0	205.1	.0	1.00	23.3	9.7	20.3	-1.9	1.42	293.9	-22.1	2.42	30.1	-2.5	.72	79.1	.0	1.73	4-4710.0
4-4720.0	214.9	.0	1.01	32.6	13.2	26.3	-1.9	1.43	300.2	-21.0	2.43	46.2	-1.7	.72	95.1	.0	1.72	4-4720.0
4-4730.0	224.6	.0	1.01	42.1	16.2	32.2	-1.5	1.44	306.3	-19.7	2.43	62.2	-1.8	.72	111.2	.0	1.71	4-4730.0
4-4740.0	234.3	.0	1.01	51.9	16.8	36.1	-1.4	1.45	312.3	-18.2	2.44	78.3	1.1	.72	127.3	.0	1.69	4-4740.0
4-4750.0	243.9	.0	1.01	61.9	20.9	43.8	-1.2	1.46	318.0	-16.8	2.44	94.5	1.1	.72	143.5	.0	1.67	4-4750.0
4-4760.0	253.5	.0	1.01	72.1	22.4	49.4	-1.0	1.47	323.6	-14.6	2.43	110.7	1.9	.72	159.7	.0	1.65	4-4760.0
4-4770.0	263.0	.0	1.02	82.4	23.3	54.9	-1.2	1.49	329.0	-12.9	2.43	126.9	2.6	.72	175.9	.0	1.63	4-4770.0
4-4780.0	272.6	.0	1.02	92.8	23.4	60.4	-1.4	1.50	334.2	-11.0	2.42	143.1	3.1	.72	192.2	.0	1.57	4-4780.0
4-4790.0	282.1	.0	1.02	103.2	22.9	65.7	-1.5	1.51	339.2	-9.0	2.41	159.4	3.4	.72	208.4	.0	1.53	4-4790.0
4-4800.0	291.7	.0	1.02	113.4	21.7	71.0	-.7	1.52	344.1	-7.0	2.39	175.6	3.3	.72	224.6	.0	1.46	4-4800.0
4-4810.0	301.2	.0	1.02	123.4	19.9	76.1	-.8	1.54	348.9	-4.9	2.37	191.8	3.1	.72	240.7	.0	1.43	4-4810.0
4-4820.0	310.8	.0	1.01	133.2	17.5	81.2	1.0	1.55	353.5	-2.9	2.34	207.9	2.5	.72	256.8	.0	1.37	4-4820.0
4-4830.0	320.3	.0	1.01	142.8	14.7	86.2	1.1	1.56	358.1	-1.6	2.31	223.9	1.8	.72	272.9	.0	1.31	4-4830.0
4-4840.0	330.0	.0	1.01	152.1	11.5	91.2	1.2	1.57	2.6	1.2	2.27	239.9	1.0	.72	288.9	.0	1.24	4-4840.0
4-4850.0	339.6	.0	1.01	161.2	8.0	96.0	1.3	1.59	7.0	3.1	2.23	255.8	0.0	.73	304.8	.0	1.18	4-4850.0
4-4860.0	349.3	.0	1.01	170.2	4.2	100.6	1.4	1.60	11.4	5.0	2.18	271.7	-.9	.73	320.7	.0	1.11	4-4860.0
4-4870.0	359.1	.0	1.00	179.2	1.4	105.5	1.5	1.61	16.6	6.9	2.12	287.5	-1.8	.73	336.5	.0	1.04	4-4870.0
4-4880.0	368.9	.0	1.00	188.2	-3.5	110.2	1.6	1.62	20.1	8.7	2.06	303.3	-2.5	.73	352.3	.0	.96	4-4880.0
4-4890.0	378.6	.0	1.00	197.3	-7.4	114.8	1.7	1.63	24.3	10.4	1.99	319.1	-3.0	.73	6.1	.0	.89	4-4890.0
4-4900.0	28.7	.0	1.00	206.7	-11.0	119.3	1.7	1.63	28.6	12.1	1.92	334.9	-3.3	.73	23.9	.0	.82	4-4900.0
4-4910.0	38.7	.0	.99	216.3	-14.4	123.9	1.8	1.64	33.1	13.7	1.85	350.8	-3.4	.73	38.8	.0	.74	4-4910.0
4-4920.0	48.7	.0	.99	226.3	-17.4	120.3	1.8	1.65	37.5	15.2	1.76	6.7	-3.2	.73	55.7	.0	.66	4-4920.0
4-4930.0	58.8	.0	.99	236.6	-19.9	132.8	1.8	1.65	41.9	16.5	1.68	22.6	-2.7	.72	71.6	.0	.59	4-4930.0
4-4940.0	68.9	.0	.99	247.2	-21.6	137.2	1.8	1.66	46.3	17.8	1.58	38.6	-2.1	.72	87.6	.0	.51	4-4940.0
4-4950.0	79.1	.0	.98	258.1	-23.0	141.6	1.8	1.66	50.8	19.0	1.49	54.7	-1.3	.72	103.6	.0	.44	4-4950.0
4-4960.0	89.2	.0	.98	269.2	-23.4	146.0	1.8	1.66	55.3	20.1	2.18	271.7	-3.0	.73	320.7	.0	.38	4-4960.0
4-4970.0	99.4	.0	.98	280.3	-23.1	150.4	1.8	1.67	59.9	21.0	1.30	86.9	-.6	.72	135.9	.0	.32	4-4970.0
4-4980.0	109.6	.0	.98	291.2	-22.0	154.7	1.8	1.67	64.5	21.9	1.20	103.0	1.5	.72	152.1	.0	.28	4-4980.0
4-4990.0	119.8	.0	.98	302.0	-20.2	159.1	1.7	1.67	69.1	22.6	1.10	119.3	2.3	.72	166.3	.0	.27	4-4990.0
4-5000.0	130.0	.0	.99	312.4	-17.8	163.5	1.7	1.66	73.8	23.1	1.00	135.5	2.9	.72	184.5	.0	.26	4-5000.0
4-5010.0	140.1	.0	.99	322.5	-14.8	167.9	1.6	1.66	76.6	23.6	.91	151.8	3.3	.72	200.0	.0	.32	4-5010.0
4-5020.0	150.2	.0	.99	332.3	-11.4	172.3	1.6	1.66	83.4	23.8	.83	168.0	3.4	.72	217.0	.0	.38	4-5020.0
4-5030.0	160.3	.0	.99	341.8	-7.7	176.7	1.5	1.65	88.2	24.0	.76	184.2	3.2	.72	233.2	.0	.44	4-5030.0
4-5040.0	170.3	.0	.99	351.1	-3.8	181.1	1.4	1.65	93.0	24.0	.70	200.3	2.8	.72	249.3	.0	.32	4-5040.0
4-5100.0	229.2	.0	1.01	46.7	17.5	208.6	1.7	1.60	122.5	20.6	.75	295.8	-2.2	.73	344.9	.0	.08	4-5100.0
4-5110.0	238.8	.0	1.01	56.6	19.9	213.3	1.8	1.59	127.5	19.4	.80	311.7	-2.6	.73	37.7	.0	1.06	4-5110.0
4-5120.0	248.4	.0	1.01	66.7	21.7	216.2	1.8	1.58	132.4	18.2	.87	327.5	-3.2	.73	16.5	.0	1.13	4-5120.0
4-5130.0	258.0	.0	1.02	77.0	22.9	223.1	1.8	1.57	137.5	18.6	.94	343.3	-3.4	.73	52.3	.0	1.20	4-5130.0
4-5140.0	267.6	.0	1.02	87.4	23.4	228.0	1.0	1.55	142.3	15.2	1.01	359.2	-3.3	.73	48.2	.0	1.27	4-5140.0
4-5150.0	277.1	.0	1.02	97.7	23.3	233.1	1.1	1.54</td										

TABLE 2-5 (CONT.)

JULIAN DATE	EARTH					MARS					VENUS					JULIAN DATE		
	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	
4-5550.0	310.3	.0	1.01	152.7	17.7	102.2	1.5	1.60	12.0	5.6	2.54	296.8	-2.2	.73	345.0	.0	.35	4-5550.0
4-5560.0	319.9	.0	1.01	142.3	14.9	106.9	1.6	1.61	17.1	7.5	2.52	312.6	-2.6	.73	1.6	.0	.31	4-5560.0
4-5570.0	329.5	.0	1.01	151.6	11.7	111.6	1.6	1.62	21.4	9.2	2.27	328.4	-3.2	.73	17.5	.0	.29	4-5570.0
4-5580.0	339.1	.0	1.01	160.7	0.1	116.2	1.7	1.63	25.8	10.9	2.46	344.3	-3.4	.73	33.3	.0	.30	4-5580.0
4-5590.0	348.0	.0	1.01	169.7	4.4	120.7	1.8	1.64	30.1	12.6	2.43	.2	-3.3	.73	49.1	.0	.33	4-5590.0
4-5600.0	358.0	.0	1.00	178.7	-6	125.2	1.6	1.64	34.5	14.1	2.38	16.1	-2.9	.73	65.0	.0	.38	4-5600.0
4-5610.0	36.4	.0	1.00	187.7	-3.3	129.7	1.6	1.65	38.8	15.6	2.33	32.1	-2.4	.72	81.0	.0	.45	4-5610.0
4-5620.0	10.3	.0	1.00	196.8	-7.2	134.1	1.6	1.65	43.2	16.9	2.27	46.1	-1.6	.72	97.0	.0	.52	4-5620.0
4-5630.0	28.2	.0	1.00	206.2	-10.8	138.5	1.6	1.66	47.7	18.2	2.21	64.1	-1.7	.72	113.1	.0	.59	4-5630.0
4-5640.0	38.2	.0	1.00	215.6	-14.2	142.9	1.6	1.66	52.1	19.4	2.14	80.2	-2	.72	129.2	.0	.67	4-5640.0
4-5650.0	48.2	.0	1.00	225.7	-17.3	147.3	1.6	1.66	56.7	20.4	2.07	96.4	1.2	.72	145.4	.0	.74	4-5650.0
4-5660.0	58.3	.0	1.00	236.0	-19.0	151.7	1.6	1.67	61.2	21.3	1.99	112.6	2.0	.72	161.6	.0	.82	4-5660.0
4-5670.0	68.4	.0	1.00	246.7	-21.7	156.1	1.6	1.67	65.9	22.1	1.90	128.8	2.7	.72	177.9	.0	.89	4-5670.0
4-5680.0	78.5	.0	1.00	257.5	-23.0	160.4	1.7	1.67	70.5	22.8	1.81	145.1	3.2	.72	194.1	.0	.96	4-5680.0
4-5690.0	88.7	.0	1.00	268.6	-23.4	164.6	1.7	1.66	75.2	23.3	1.72	161.3	3.4	.72	210.3	.0	1.03	4-5690.0
4-5700.0	98.9	.0	1.00	279.7	-23.2	169.2	1.6	1.66	80.0	23.7	1.62	177.6	3.3	.72	226.5	.0	1.10	4-5700.0
4-5710.0	109.1	.0	1.00	290.7	-22.1	173.6	1.5	1.66	84.8	23.9	1.52	193.7	3.0	.72	242.7	.0	1.16	4-5710.0
4-5720.0	119.3	.0	1.00	301.4	-20.3	178.0	1.4	1.65	89.6	24.0	1.42	209.8	2.5	.72	259.8	.0	1.23	4-5720.0
4-5730.0	129.5	.0	1.00	311.9	-17.9	182.5	1.3	1.65	94.3	23.9	1.32	225.9	1.7	.72	274.8	.0	1.29	4-5730.0
4-5740.0	139.6	.0	1.00	322.0	-14.9	186.9	1.2	1.64	99.4	23.7	1.21	241.8	.9	.73	290.8	.0	1.34	4-5740.0
4-5750.0	149.7	.0	1.00	331.8	-11.6	191.5	1.1	1.63	104.3	23.3	1.11	257.7	-1.1	.73	306.7	.0	1.40	4-5750.0
4-5760.0	159.8	.0	1.00	341.3	-7.9	196.0	1.0	1.63	109.2	22.8	1.01	273.5	-1.0	.73	322.6	.0	1.45	4-5760.0
4-5770.0	169.8	.0	1.00	350.6	-4.1	200.6	0	1.62	114.2	22.1	.92	289.4	-1.9	.73	336.4	.0	1.49	4-5770.0
4-5780.0	179.7	.0	1.00	359.8	-0.1	205.3	0	1.61	119.1	21.2	.83	305.2	-2.6	.73	354.2	.0	1.54	4-5780.0
4-5790.0	189.6	.0	1.00	36.9	3.8	210.0	0	1.60	124.0	20.2	.75	321.0	-3.1	.73	370.0	.0	1.58	4-5790.0
4-5800.0	199.5	.0	1.00	18.0	7.6	214.8	0	1.59	129.0	19.1	.67	336.8	-3.3	.73	25.8	.0	1.61	4-5800.0
4-5810.0	209.5	.0	1.00	27.2	11.2	219.6	0	1.57	133.9	17.8	.61	352.7	-3.4	.73	41.7	.0	1.65	4-5810.0
4-5820.0	219.0	.0	1.01	36.6	14.5	224.6	0	1.55	138.6	16.3	.57	36.6	-3.1	.73	57.6	.0	1.67	4-5820.0
4-5830.0	228.7	.0	1.01	46.2	17.4	229.6	0	1.55	143.7	14.7	.54	24.6	-2.7	.72	73.5	.0	1.70	4-5830.0
4-5840.0	238.3	.0	1.01	56.1	19.6	234.6	-2	1.54	148.7	13.0	.53	40.5	-2.0	.72	89.5	.0	1.71	4-5840.0
4-5850.0	248.0	.0	1.01	66.2	21.6	239.8	-3	1.52	153.6	11.2	.54	56.6	-1.1	.72	105.5	.0	1.73	4-5850.0
4-5860.0	257.5	.0	1.02	76.4	23.9	245.1	-5	1.51	158.6	9.2	.56	72.7	-2	.72	121.6	.0	1.73	4-5860.0
4-5870.0	267.1	.0	1.02	86.8	23.4	250.4	-7	1.50	163.6	7.2	.60	88.6	-2.7	.72	137.8	.0	1.74	4-5870.0
4-5880.0	276.6	.0	1.02	97.2	23.3	255.9	-8	1.49	168.6	5.0	.64	105.0	1.6	.72	154.0	.0	1.73	4-5880.0
4-5890.0	286.2	.0	1.02	107.5	22.5	261.4	-10	1.47	173.7	2.8	.70	121.2	2.4	.72	170.2	.0	1.72	4-5890.0
4-5900.0	295.7	.0	1.02	117.7	21.0	267.0	-11	1.46	178.8	-5	.75	137.4	3.0	.72	186.5	.0	1.70	4-5900.0
4-5910.0	305.2	.0	1.02	127.6	19.0	272.8	-13	1.45	184.1	-1	.60	153.7	3.3	.72	202.7	.0	1.66	4-5910.0
4-5920.0	314.8	.0	1.01	137.3	16.4	278.6	-14	1.44	189.4	-4	.26	169.9	3.4	.72	218.9	.0	1.65	4-5920.0
4-5930.0	324.4	.0	1.01	146.7	13.4	284.5	-15	1.43	194.9	-6	.92	186.1	3.2	.72	235.1	.0	1.62	4-5930.0
4-5940.0	334.0	.0	1.01	159.9	10.0	290.5	-16	1.42	200.4	-8	.98	202.3	2.7	.72	251.2	.0	1.58	4-5940.0
4-5950.0	343.7	.0	1.01	165.0	6.4	296.6	-17	1.41	206.2	-11.1	1.03	218.3	2.1	.72	267.3	.0	1.54	4-5950.0
4-5960.0	353.5	.0	1.01	174.0	2.6	302.7	-18	1.40	212.0	-13.3	1.09	234.3	1.3	.72	283.3	.0	1.50	4-5960.0
4-5970.0	363.2	.0	1.00	185.0	-1.3	308.9	-18	1.39	210.1	-15.3	1.15	250.2	-1.4	.73	299.2	.0	1.45	4-5970.0
4-5980.0	13.1	.0	1.00	192.0	-5.2	315.2	-18	1.39	224.3	-17.3	1.21	266.1	-1.6	.73	315.1	.0	1.40	4-5980.0
4-5990.0	23.0	.0	1.00	201.2	-8.9	321.5	-18	1.38	230.7	-19.0	1.26	281.9	-1.5	.73	331.0	.0	1.34	4-5990.0
4-6000.0	32.9	.0	1.00	210.7	-12.5	327.8	-18	1.38	237.2	-20.5	1.32	297.7	-2.2	.73	346.8	.0	1.28	4-6000.0
4-6010.0	42.9	.0	1.00	220.5	-15.7	334.2	-19	1.38	243.9	-21.8	1.38	313.6	-2.9	.73	2.6	.0	1.22	4-6010.0
4-6020.0	52.0	.0	1.00	230.6	-18.5	340.5	-20	1.37	250.6	-22.8	1.44	329.4	-3.2	.73	18.4	.0	1.16	4-6020.0
4-6030.0	62.1	.0	1.00	241.0	-20.8	346.9	-21	1.36	257.5	-23.5	1.50	345.2	-3.4	.73	34.2	.0	1.10	4-6030.0
4-6040.0	72.2	.0	1.00	251.1	-22.4	353.2	-22	1.35	264.4	-23.9	1.56	31.1	-3.3	.73	50.1	.0	1.03	4-6040.0
4-6050.0	82.4	.0	1.00	252.6	-23.3	359.4	-14	1.39	271.2	-24.0	1.62	297.7	-2.2	.73	66.0	.0	.96	4-6050.0
4-6060.0	92.6	.0	1.00	273.9	-23.4	357.8	-5	1.37	278.0	-23.6	1.60	330.0	-2.5	.72	82.0	.0	.89	4-6060.0
4-6070.0	102.7	.0	1.00	284.9	-22.7	365.8	-4	1.36	284.7	-23.5	1.74	49.0	-1.6	.72	99.0	.0	.82	4-6070.0
4-6080.0	113.9	.0	1.00	295.6	-21.3	37.9	-10	1.35	291.3	-22.5	1.80	65.1	-1.7	.72	114.1	.0	.74	4-6080.0
4-6090.0	124.1	.0	1.00	306.4	-19.2	40.0	-12	1.34	297.7	-21.5	1.87	81.8	-1.3	.72	130.2	.0	.67	4-6090.0
4-6100.0	134.3	.0	1.00	316.7	-16.6	29.9	-16	1.34	303.9	-20.3	1.93	97.4	1.2	.72	146.4	.0	.60	4-6100.0
4-6110.0	144.4	.0	1.00	326.7	-13.4	35.8	-14	1.34	310.0	-18.0	1.99	113.6	2.1	.72	162.6	.0	.52	4-6110.0
4-6120.0	154.5	.0	1.00	336.3	-9.9	41.5	-12	1.36	315.8	-17.2	2.05	129.8	2.7	.72	178.0	.0	.45	4-6120.0
4-6130.0	164.5	.0	1.00	345.7	-6.1	47.2	-11	1.37	321.4	-15.3	2.12	146.1	3.2	.72	195.1	.0	.39	4-6130.0
4-6140.0	174.5	.0	1.00	355.0	-2.2	52.8	-10	1.38	326.9	-15.7	2.17	162.3	3.4	.72	211.3	.0	.33	4-6140.0
4-6150.0	184.4	.0	1.00	4.1	1.8	58.2	-9	1.39	332.1	-11.0	2							

TABLE 2-5 (CONT.)

JULIAN DATE	EARTH						MARS						VENUS						JULIAN DATE
	PLAN	PLAN	SUN	SUN	PLAN	PLAN	SUN	SUN	COM	PLAN	PLAN	SUN	SUN	COM	PLAN	PLAN	VENUS		
	LONG	LAT	R	RA	LONG	LAT	R	RA	DECL	LONG	LAT	R	RA	DECL	DIST	LONG	RA	JULIAN DATE	
4-6600.0	366.6	.0	1.02	86.3	23.4	274.5	-1.3	1.44	185.7	-2.5	.46	179.5	3.3	.72	228.5	.0	1.22	4-6600.0	
4-6610.0	276.1	.0	1.02	96.7	23.3	280.4	-1.4	1.43	191.0	-4.9	.43	195.7	3.0	.72	244.6	.0	1.15	4-6610.0	
4-6620.0	285.7	.0	1.02	107.0	22.5	288.3	-1.6	1.42	196.5	-7.2	.41	211.8	2.4	.72	260.7	.0	1.07	4-6620.0	
4-6630.0	295.2	.0	1.02	117.2	21.1	292.3	-1.6	1.41	202.2	-9.5	.40	227.8	1.6	.72	276.7	.0	1.00	4-6630.0	
4-6640.0	304.8	.0	1.02	127.1	19.1	298.4	-1.7	1.41	207.9	-11.8	.41	243.7	.7	.73	292.7	.0	.92	4-6640.0	
4-6650.0	314.3	.0	1.01	136.8	16.5	304.6	-1.0	1.40	213.9	-13.9	.44	259.6	-2	.73	308.6	.0	.84	4-6650.0	
4-6660.0	323.9	.0	1.01	146.2	13.6	310.8	-1.0	1.39	219.9	-19.9	.47	275.4	-1.1	.73	324.5	.0	.76	4-6660.0	
4-6670.0	333.6	.0	1.01	155.5	10.2	317.1	-1.0	1.39	226.2	-17.0	.51	291.3	1.9	.73	340.3	.0	.68	4-6670.0	
4-6680.0	343.2	.0	1.01	164.5	6.6	323.4	-1.0	1.38	232.6	-19.5	.56	307.1	-2.6	.73	356.1	.0	.60	4-6680.0	
4-6690.0	353.0	.0	1.01	173.5	2.8	329.7	-1.0	1.38	239.2	-20.9	.61	322.9	-3.1	.73	311.9	.0	.53	4-6690.0	
4-6700.0	2.7	.0	1.00	182.5	-1.1	336.1	-1.0	1.38	245.9	-22.1	.66	338.7	-3.4	.73	27.7	.0	.45	4-6700.0	
4-6710.0	12.6	.0	1.00	191.6	-5.0	342.4	-1.7	1.38	252.7	-23.0	.72	354.6	-3.4	.73	43.6	.0	.38	4-6710.0	
4-6720.0	22.5	.0	1.00	200.8	-8.7	348.8	-1.6	1.38	259.6	-23.6	.78	10.5	-3.1	.73	59.5	.0	.33	4-6720.0	
4-6730.0	32.4	.0	1.00	210.2	-12.3	355.1	-1.5	1.39	266.4	-23.9	.85	26.5	-2.6	.72	75.4	.0	.29	4-6730.0	
4-6740.0	42.4	.0	1.00	220.0	-15.6	1.3	-1.4	1.39	273.3	-23.9	.92	42.5	-1.9	.72	91.4	.0	.27	4-6740.0	
4-6750.0	52.5	.0	1.00	230.0	-18.4	7.5	-1.2	1.40	280.1	-23.7	.99	58.5	-1.0	.72	107.5	.0	.26	4-6750.0	
4-6760.0	62.6	.0	1.00	240.5	-20.7	13.7	-1.1	1.41	206.7	-23.1	1.06	74.6	-1	.72	123.6	.0	.22	4-6760.0	
4-6770.0	72.7	.0	1.00	251.2	-22.3	19.6	-1.0	1.42	293.3	-22.2	1.14	90.7	.8	.72	139.7	.0	.17	4-6770.0	
4-6780.0	82.8	.0	1.00	262.2	-23.3	25.8	-0.7	1.43	299.6	-21.1	1.21	106.9	1.7	.72	155.9	.0	.14	4-6780.0	
4-6790.0	93.0	.0	1.00	273.3	-23.4	31.7	-0.6	1.44	305.6	-19.8	1.29	123.1	2.5	.72	172.2	.0	.11	4-6790.0	
4-6800.0	103.2	.0	1.00	284.4	-22.0	37.5	-0.4	1.43	311.7	-18.4	1.38	139.4	3.0	.72	188.4	.0	.09	4-6800.0	
4-6810.0	113.4	.0	1.00	293.3	-21.4	45.2	-0.2	1.44	317.5	-16.7	1.46	155.6	3.3	.72	204.7	.0	.06	4-6810.0	
4-6820.0	123.6	.0	1.00	305.9	-19.4	48.9	0	1.47	323.1	-15.0	1.54	171.9	3.4	.72	220.9	.0	.04	4-6820.0	
4-6830.0	133.7	.0	1.00	316.2	-16.7	54.4	2	1.48	328.5	-13.1	1.62	188.1	3.2	.72	237.0	.0	.01	4-6830.0	
4-6840.0	143.9	.0	1.00	326.2	-13.6	59.9	3	1.50	333.7	-11.2	1.71	204.2	2.7	.72	253.1	.0	.00	4-6840.0	
4-6850.0	154.0	.0	1.00	335.9	-10.1	65.2	5	1.51	338.7	-9.2	1.79	220.2	2.0	.72	269.2	.0	.00	4-6850.0	
4-6860.0	164.0	.0	1.00	345.3	-6.3	70.5	7	1.52	343.6	-7.1	1.87	236.2	1.2	.72	285.2	.0	1.03	4-6860.0	
4-6870.0	174.0	.0	1.00	354.5	-2.4	75.7	8	1.54	348.4	-5.1	1.95	252.1	0.2	.73	301.1	.0	1.10	4-6870.0	
4-6880.0	185.9	.0	1.00	364.0	3.6	80.8	10	1.55	353.1	-3.1	2.02	268.0	-0.7	.73	317.0	.0	1.17	4-6880.0	
4-6890.0	195.0	.0	1.00	12.7	5.5	85.8	11	1.56	357.7	-1.0	2.10	285.8	-1.6	.73	332.9	.0	1.24	4-6890.0	
4-6900.0	203.6	.0	1.00	21.9	9.2	90.7	12	1.57	22.2	1.0	2.17	299.6	-2.3	.73	348.7	.0	1.30	4-6900.0	
4-6910.0	213.4	.0	1.01	31.2	12.7	95.6	13	1.58	6.6	2.9	2.24	315.4	-2.9	.73	45.5	.0	1.60	4-6910.0	
4-6920.0	223.1	.0	1.01	40.7	15.8	100.3	14	1.60	11.0	4.9	2.30	331.3	-3.3	.73	20.3	.0	1.38	4-6920.0	
4-6930.0	232.8	.0	1.01	50.4	18.5	105.1	15	1.61	15.4	6.7	2.36	347.1	-3.4	.73	36.1	.0	1.47	4-6930.0	
4-6940.0	242.4	.0	1.01	60.3	20.7	109.7	16	1.62	19.7	8.5	2.42	3.0	0.3	.73	52.0	.0	1.52	4-6940.0	
4-6950.0	252.0	.0	1.01	70.5	22.2	114.3	17	1.62	24.1	10.3	2.47	19.0	-2.9	.73	67.9	.0	1.56	4-6950.0	
4-6960.0	261.6	.0	1.02	80.6	23.2	118.9	18	1.63	26.4	11.9	2.52	34.9	-2.2	.72	83.9	.0	1.60	4-6960.0	
4-6970.0	271.1	.0	1.02	91.2	23.4	123.4	19	1.64	32.7	13.5	2.56	51.0	-1.5	.72	99.9	.0	1.64	4-6970.0	
4-6980.0	280.7	.0	1.02	101.6	23.0	127.9	20	1.65	37.1	15.0	2.59	67.0	-1.5	.72	116.0	.0	1.67	4-6980.0	
4-6990.0	290.2	.0	1.02	111.8	21.9	132.4	21	1.65	41.5	16.4	2.62	83.1	-1.4	.72	132.1	.0	1.69	4-6990.0	
4-7000.0	299.7	.0	1.02	121.9	20.2	136.8	22	1.66	45.9	17.7	2.64	99.3	1.3	.72	148.3	.0	1.71	4-7000.0	
4-7010.0	309.3	.0	1.01	131.7	17.9	141.2	23	1.66	50.4	18.9	2.66	115.5	2.1	.72	164.5	.0	1.72	4-7010.0	
4-7020.0	318.9	.0	1.01	141.3	15.2	145.6	24	1.66	54.9	20.0	2.67	131.7	2.8	.72	180.8	.0	1.73	4-7020.0	
4-7030.0	328.5	.0	1.01	150.6	12.0	150.0	25	1.67	59.4	21.0	2.68	148.0	3.2	.72	197.0	.0	1.73	4-7030.0	
4-7040.0	338.1	.0	1.01	159.8	8.5	154.3	26	1.67	64.0	21.8	2.67	164.2	3.4	.72	213.2	.0	1.73	4-7040.0	
4-7050.0	347.6	.0	1.01	168.8	4.0	158.7	27	1.67	66.7	22.5	2.66	180.5	3.5	.72	229.4	.0	1.72	4-7050.0	
4-7060.0	357.6	.0	1.00	177.8	1.0	165.1	28	1.67	73.4	23.1	2.67	196.6	2.9	.72	245.6	.0	1.70	4-7060.0	
4-7070.0	7.4	.0	1.00	186.8	-2.9	167.4	29	1.66	78.1	23.5	2.63	212.7	2.3	.72	261.7	.0	1.68	4-7070.0	
4-7080.0	17.3	.0	1.00	195.9	-6.8	171.0	30	1.66	82.9	23.8	2.60	228.7	1.7	.72	277.7	.0	1.66	4-7080.0	
4-7090.0	27.2	.0	1.00	205.2	-10.9	176.3	31	1.65	87.7	24.7	2.56	244.7	1.7	.73	293.6	.0	1.63	4-7090.0	
4-7100.0	37.1	.0	1.00	214.8	-13.9	180.7	32	1.65	92.6	24.0	2.52	260.6	-3	.73	309.5	.0	1.60	4-7100.0	
4-7110.0	47.2	.0	1.00	224.7	-17.0	185.2	33	1.64	97.5	23.8	2.47	274.6	-1.2	.73	325.4	.0	1.57	4-7110.0	
4-7120.0	57.2	.0	1.00	235.0	-19.6	189.7	34	1.64	102.4	23.5	2.42	292.2	-2.0	.73	341.2	.0	1.53	4-7120.0	
4-7130.0	67.4	.0	1.00	245.5	-21.5	194.2	35	1.63	107.3	23.0	2.36	308.0	-2.7	.73	357.1	.0	1.49	4-7130.0	
4-7140.0	77.5	.0	1.00	256.4	-22.9	198.6	36	1.62	112.2	22.4	2.29	323.8	-3.1	.73	37.9	.0	1.44	4-7140.0	
4-7150.0	87.7	.0	1.00	267.5	-23.4	203.4	37	1.61	117.2	21.6	2.22	339.7	-3.4	.73	28.7	.0	1.39	4-7150.0	
4-7160.0	97.9	.0	1.00	278.6	-23.2	208.1	38	1.60	122.1	20.7	2.15	355.6	-3.4	.73	44.5	.0	1.34	4-7160.0	
4-7170.0	108.1	.0	1.00	289.6	-22.2	212.9	39	1.59	127.0	19.6	2.07	115.5	-3.1	.73	60.4	.0	1.29	4-7170.0	
4-7180.0	118.2	.0	1.00	300.4	-20.5	217.7	40	1.58	131.9	18.3	1.99	27.4	-2.6	.72	76.4	.0	1.23	4-7180.0	
4-7190.0	128.4	.0	1.00	310.8	-18.2	222.6	41	1.57	136.9	16.9	1.91	43.4	-1.8	.72	92				

TABLE 2-5 (CONT.)

3 MAY 89

3 MAY 89

JULIAN DATE	EARTH					MARS					VENUS					JULIAN DATE		
	PLAN	PLAN	SUN	SUN	COM	PLAN	PLAN	SUN	SUN	COM	PLAN	PLAN	SUN	SUN	COM			
LONG	LAT	R	RA	DECL	LONG	LAT	R	RA	DECL	LONG	LAT	R	RA	DECL	DIST			
4-7650.0	222.6	.0	1.01	40.2	15.6	120.3	1.7	1.64	29.7	12.4	2.10	60.4	-1.9	.72	109.4	.0	1.71	4-7650.0
4-7660.0	232.3	.0	1.01	49.9	18.4	124.0	1.8	1.64	34.0	14.0	2.17	76.5	-1.0	.72	125.5	.0	1.69	4-7660.0
4-7670.0	241.9	.0	1.01	59.6	20.6	129.3	1.8	1.65	38.4	15.5	2.24	92.7	-1.0	.72	141.7	.0	1.67	4-7670.0
4-7680.0	251.5	.0	1.01	70.0	22.2	133.7	1.8	1.65	42.6	16.8	2.31	108.9	-1.8	.72	157.9	.0	1.64	4-7680.0
4-7690.0	261.1	.0	1.02	80.3	23.1	138.1	1.8	1.66	47.3	18.1	2.37	125.1	-2.6	.72	174.1	.0	1.61	4-7690.0
4-7700.0	270.6	.0	1.02	90.7	23.4	142.5	1.8	1.66	51.7	19.3	2.42	141.3	-3.1	.72	190.4	.0	1.57	4-7700.0
4-7710.0	280.2	.0	1.02	101.1	23.1	146.9	1.8	1.66	56.2	20.3	2.47	157.6	-3.4	.72	206.6	.0	1.53	4-7710.0
4-7720.0	289.7	.0	1.02	111.3	22.0	151.3	1.8	1.67	60.6	21.2	2.52	173.8	-3.4	.72	222.8	.0	1.48	4-7720.0
4-7730.0	299.2	.0	1.02	121.4	20.3	155.6	1.8	1.67	65.4	22.0	2.56	190.0	-3.1	.72	239.0	.0	1.43	4-7730.0
4-7740.0	308.8	.0	1.01	131.2	18.1	160.0	1.7	1.67	70.1	22.7	2.59	206.1	-2.0	.72	255.1	.0	1.37	4-7740.0
4-7750.0	318.4	.0	1.01	140.6	15.3	164.4	1.7	1.66	74.8	23.2	2.61	222.2	-1.9	.72	271.1	.0	1.31	4-7750.0
4-7760.0	328.0	.0	1.01	150.2	12.2	168.8	1.8	1.66	79.6	23.6	2.63	238.1	-1.1	.72	287.1	.0	1.24	4-7760.0
4-7770.0	337.6	.0	1.01	159.3	9.7	173.2	1.5	1.66	84.4	23.9	2.64	254.0	-0.1	.73	303.0	.0	1.16	4-7770.0
4-7780.0	347.3	.0	1.01	168.4	5.0	177.6	1.5	1.65	89.2	24.0	2.65	269.9	-0.8	.73	318.9	.0	1.11	4-7780.0
4-7790.0	357.1	.0	1.00	177.3	1.2	182.0	1.4	1.65	94.1	23.9	2.65	285.7	-1.7	.73	334.8	.0	1.03	4-7790.0
4-7800.0	6.9	.0	1.00	186.3	-2.7	186.5	1.3	1.64	98.9	23.7	2.64	301.5	-2.4	.73	350.6	.0	.96	4-7800.0
4-7810.0	16.7	.0	1.00	195.4	-6.6	191.0	1.1	1.63	105.9	25.4	2.63	317.3	-3.0	.73	36.4	.0	.89	4-7810.0
4-7820.0	26.7	.0	1.00	204.7	-10.3	195.6	1.0	1.63	106.8	22.8	2.61	335.2	-3.3	.73	22.2	.0	.81	4-7820.0
4-7830.0	36.6	.0	1.00	214.3	-13.7	200.2	0.9	1.62	113.7	22.2	2.58	349.0	-3.4	.73	38.0	.0	.74	4-7830.0
4-7840.0	46.7	.0	1.00	224.2	-16.8	204.8	0.8	1.61	118.6	21.3	2.55	4.9	-3.2	.73	53.9	.0	.66	4-7840.0
4-7850.0	56.7	.0	1.00	234.4	-19.4	209.6	0.6	1.60	123.6	20.3	2.58	20.9	-2.8	.72	69.8	.0	.58	4-7850.0
4-7860.0	66.6	.0	1.00	243.0	-21.5	214.3	0.5	1.59	128.3	19.2	2.48	36.8	-2.2	.72	85.8	.0	.51	4-7860.0
4-7870.0	77.0	.0	1.00	253.9	-22.8	219.2	0.4	1.58	133.4	17.9	2.43	52.9	-1.4	.72	101.8	.0	.44	4-7870.0
4-7880.0	87.2	.0	1.00	266.9	-23.4	224.1	0.3	1.56	138.4	16.5	2.36	68.9	-1.4	.72	117.9	.0	.37	4-7880.0
4-7890.0	97.3	.0	1.00	276.0	-23.2	229.1	0.0	1.55	145.3	14.9	2.32	85.1	-1.5	.72	134.1	.0	.32	4-7890.0
4-7900.0	107.5	.0	1.00	289.0	-22.3	234.2	-0.2	1.54	148.2	13.2	2.27	101.2	-1.4	.72	150.3	.0	.28	4-7900.0
4-7910.0	117.7	.0	1.00	299.3	-20.6	239.3	-0.3	1.53	153.2	11.4	2.21	117.5	-2.6	.72	165.5	.0	.27	4-7910.0
4-7920.0	127.9	.0	1.00	310.3	-18.3	244.6	-0.5	1.51	158.1	9.4	2.14	133.7	-2.7	.72	182.7	.0	.26	4-7920.0
4-7930.0	138.0	.0	1.00	320.5	-15.4	249.9	-0.7	1.50	163.1	7.4	2.08	149.9	-3.3	.72	199.0	.0	.32	4-7930.0
4-7940.0	148.1	.0	1.00	330.3	-12.1	255.3	-0.8	1.49	168.1	5.2	2.01	166.2	-3.4	.72	215.2	.0	.30	4-7940.0
4-7950.0	158.2	.0	1.00	339.9	-9.5	260.9	-1.0	1.47	175.2	3.0	1.95	182.4	-3.3	.72	231.4	.0	.45	4-7950.0
4-7960.0	168.2	.0	1.00	349.2	-4.7	266.5	-1.1	1.46	178.4	-0.7	1.88	198.6	-2.9	.72	247.5	.0	.52	4-7960.0
4-7970.0	178.2	.0	1.00	358.4	-1.7	272.2	-1.3	1.45	183.6	-1.0	1.81	214.6	-2.3	.72	263.6	.0	.60	4-7970.0
4-7980.0	188.1	.0	1.00	367.5	3.2	278.0	-1.4	1.44	188.9	-3.9	1.75	230.6	-1.5	.72	279.6	.0	.68	4-7980.0
4-7990.0	198.0	.0	1.00	18.6	7.1	283.9	-1.5	1.43	194.3	-6.3	1.68	246.6	-0.6	.73	295.5	.0	.75	4-7990.0
4-8000.0	207.0	.0	1.00	25.6	10.7	289.9	-1.6	1.42	199.1	-8.6	1.62	262.4	-0.4	.73	311.5	.0	.83	4-8000.0
4-8010.0	217.5	.0	1.01	35.2	14.0	296.0	-1.7	1.41	205.6	-10.9	1.56	278.3	-1.3	.73	327.3	.0	.91	4-8010.0
4-8020.0	227.2	.0	1.01	44.7	17.0	302.1	-1.8	1.40	211.5	-13.1	1.50	294.1	-2.1	.73	343.1	.0	.99	4-8020.0
4-8030.0	236.9	.0	1.01	54.6	19.5	308.3	-1.8	1.39	217.5	-15.2	1.44	309.9	-2.7	.73	358.9	.0	1.06	4-8030.0
4-8040.0	246.5	.0	1.01	64.6	21.4	314.6	-1.8	1.39	223.7	-17.1	1.38	325.7	-3.2	.73	374.8	.0	1.13	4-8040.0
4-8050.0	256.1	.0	1.01	74.9	22.7	320.9	-1.8	1.39	230.1	-18.8	1.32	341.6	-3.4	.73	30.6	.0	1.20	4-8050.0
4-8060.0	265.6	.0	1.02	85.2	23.4	327.2	-1.8	1.38	236.6	-20.4	1.27	357.5	-3.3	.73	46.4	.0	1.27	4-8060.0
4-8070.0	275.2	.0	1.02	95.6	23.3	335.6	-1.8	1.38	243.2	-21.7	1.21	313.4	-3.0	.73	62.3	.0	1.33	4-8070.0
4-8080.0	284.7	.0	1.02	105.9	22.6	339.9	-1.7	1.38	250.0	-22.7	1.16	293.3	-2.5	.72	78.3	.0	1.39	4-8080.0
4-8090.0	294.2	.0	1.02	116.1	21.3	346.3	-1.6	1.38	256.8	-23.4	1.10	45.3	-1.7	.72	94.3	.0	1.44	4-8090.0
4-8100.0	303.8	.0	1.02	126.1	19.3	352.6	-1.5	1.39	263.7	-23.9	1.05	61.4	-0.9	.72	110.3	.0	1.49	4-8100.0
4-8110.0	313.3	.0	1.02	136.8	16.0	358.9	-1.4	1.39	270.0	-24.0	0.99	77.5	-1.1	.72	126.5	.0	1.54	4-8110.0
4-8120.0	322.9	.0	1.02	145.3	13.9	352.9	-1.3	1.40	277.4	-23.8	0.94	93.6	-1.0	.72	142.7	.0	1.58	4-8120.0
4-8130.0	332.6	.0	1.01	154.5	10.6	113.1	-1.1	1.40	284.1	-23.3	0.88	109.8	-1.9	.72	158.9	.0	1.51	4-8130.0
4-8140.0	342.2	.0	1.01	163.6	7.0	174.4	-1.0	1.41	290.7	-22.6	0.83	126.1	-2.6	.72	175.1	.0	1.54	4-8140.0
4-8150.0	352.0	.0	1.01	172.6	3.2	234.4	-0.8	1.42	297.1	-21.6	0.77	142.3	-3.1	.72	191.3	.0	1.67	4-8150.0
4-8160.0	1.7	.0	1.00	181.6	-7	294.4	-0.6	1.43	303.4	-20.4	0.72	158.6	-3.4	.72	207.6	.0	1.69	4-8160.0
4-8170.0	11.6	.0	1.00	190.0	-6.6	352.4	-0.4	1.44	309.4	-19.0	0.66	174.8	-3.4	.72	223.8	.0	1.70	4-8170.0
4-8180.0	21.4	.0	1.00	199.8	-8.4	41.0	-0.3	1.45	315.3	-17.4	0.61	191.0	-3.1	.72	239.9	.0	1.71	4-8180.0
4-8190.0	31.4	.0	1.00	209.2	-12.0	46.7	-0.1	1.47	320.9	-15.7	0.57	207.1	-1.7	.73	355.7	.0	1.71	4-8190.0
4-8200.0	41.4	.0	1.00	218.9	-15.3	52.2	-0.1	1.48	326.4	-13.8	0.54	223.1	-1.9	.72	272.1	.0	1.71	4-8200.0
4-8210.0	51.4	.0	1.00	229.0	-18.1	57.7	-0.3	1.49	331.6	-11.9	0.52	239.1	-1.0	.72	288.1	.0	1.71	4-8210.0
4-8220.0	61.5	.0	1.00	239.4	-20.5	63.1	-0.4	1.51	336.7	-10.0	0.52	255.0	-1.1	.73	304.0	.0	1.70	4-8220.0
4-8230.0	71.6	.0	1.00	250.1	-22.2	68.4	-0.6	1.52	341.7	-7.9	0.54	270.8	-0.9	.72	319.9	.0	1.69	4-8230.0
4-8240.0	81.8	.0	1.00	261.1	-23.2	73.6	-0.8	1.53	346.5	-5.9	0							

TABLE 2-5 (CONT.)

EARTH										MARS										VENUS	
JULIAN DATE	PLAN LONG	PLAN LAT	R	SUN RA	SUN DECL	PLAN LONG	PLAN LAT	R	SUN RA	SUN DECL	COM DIST	PLAN LONG	PLAN LAT	R	SUN RA	SUN DECL	COM DIST	JULIAN DATE			
4-8700.0	177.7	.0	1.00	357.9	-9	297.0	-1.7	1.41	207.4	-11.6	2.09	303.4	-2.5	.73	352.5	.0	1.54	4-8700.0			
4-8710.0	187.6	.0	1.00	7.0	3.0	304.0	-1.6	1.40	213.3	-13.7	2.05	319.2	-3.0	.73	8.5	.0	1.58	4-8710.0			
4-8720.0	197.5	.0	1.00	16.1	6.9	310.2	-1.6	1.39	219.4	-15.6	2.01	335.1	-3.3	.73	24.1	.0	1.61	4-8720.0			
4-8730.0	207.3	.0	1.00	25.3	10.5	316.5	-1.6	1.39	225.6	-17.6	1.96	350.9	-3.4	.73	39.9	.0	1.65	4-8730.0			
4-8740.0	217.0	.0	1.01	34.7	13.9	322.6	-1.6	1.38	231.9	-19.2	1.92	36.8	-3.2	.73	55.0	.0	1.67	4-8740.0			
4-8750.0	226.7	.0	1.01	44.3	16.8	329.1	-1.6	1.38	238.6	-20.8	1.88	22.6	-2.7	.72	71.7	.0	1.70	4-8750.0			
4-8760.0	236.4	.0	1.01	54.1	19.4	335.3	-1.6	1.38	245.3	-22.0	1.84	38.8	-2.1	.72	87.7	.0	1.71	4-8760.0			
4-8770.0	246.0	.0	1.01	64.1	21.3	341.0	-1.7	1.38	252.1	-22.9	1.80	54.8	-1.2	.72	103.8	.0	1.73	4-8770.0			
4-8780.0	255.6	.0	1.01	74.3	22.7	348.2	-1.6	1.38	259.9	-23.6	1.75	70.9	-3	.72	119.9	.0	1.73	4-8780.0			
4-8790.0	265.1	.0	1.02	84.7	23.4	354.5	-1.6	1.39	265.8	-23.9	1.71	87.0	.6	.72	136.0	.0	1.74	4-8790.0			
4-8800.0	274.7	.0	1.02	95.1	23.4	.7	-1.4	1.39	272.6	-24.0	1.07	103.2	1.5	.72	152.2	.0	1.73	4-8800.0			
4-8810.0	284.2	.0	1.02	105.4	22.7	7.0	-1.2	1.40	279.4	-23.7	1.62	119.4	2.3	.72	168.4	.0	1.72	4-8810.0			
4-8820.0	293.7	.0	1.02	115.6	21.4	13.1	-1.1	1.41	286.1	-23.1	1.31	135.6	2.9	.72	184.7	.0	1.70	4-8820.0			
4-8830.0	303.3	.0	1.02	125.6	19.4	19.2	-9	1.42	292.7	-22.3	1.53	151.9	3.3	.72	200.9	.0	1.68	4-8830.0			
4-8840.0	312.8	.0	1.01	135.3	17.0	25.2	-8	1.42	299.0	-21.3	1.48	168.1	3.4	.72	217.1	.0	1.65	4-8840.0			
4-8850.0	322.4	.0	1.01	144.8	14.0	31.1	-6	1.44	305.2	-20.0	1.42	184.3	3.2	.72	233.3	.0	1.62	4-8850.0			
4-8860.0	332.1	.0	1.01	154.1	10.7	37.0	-4	1.45	311.2	-18.5	1.37	200.5	2.6	.72	249.4	.0	1.58	4-8860.0			
4-8870.0	341.7	.0	1.01	163.2	7.2	42.7	-2	1.46	317.0	-16.9	1.31	216.6	2.2	.72	265.5	.0	1.54	4-8870.0			
4-8880.0	351.5	.0	1.01	172.2	5.4	48.4	0	1.47	322.6	-15.1	1.25	232.5	1.4	.72	281.5	.0	1.50	4-8880.0			
4-8890.0	1.2	0	1.00	181.1	-5	53.9	2	1.48	328.0	-13.3	1.18	248.5	5	.73	297.5	.0	1.45	4-8890.0			
4-8900.0	11.1	0	1.00	190.2	-4.4	59.4	3	1.50	333.2	-11.3	1.12	264.3	-5	.73	313.4	.0	1.40	4-8900.0			
4-8910.0	20.9	0	1.00	199.3	-8.2	64.7	5	1.51	338.5	-9.4	1.05	280.2	-1.4	.73	329.2	.0	1.34	4-8910.0			
4-8920.0	30.9	0	1.00	208.7	-11.8	70.0	7	1.52	343.2	-7.5	0.98	296.0	-2.2	.73	345.0	.0	1.28	4-8920.0			
4-8930.0	40.9	0	1.00	218.4	-15.1	75.2	8	1.53	348.0	-5.3	0.91	311.8	-2.8	.73	361.8	.0	1.22	4-8930.0			
4-8940.0	50.8	0	1.00	228.1	-18.0	80.3	10	1.55	352.7	-3.3	0.84	327.6	-3.2	.73	376.6	.0	1.16	4-8940.0			
4-8950.0	61.0	0	1.00	238.9	-20.4	85.3	11	1.56	357.3	-1.2	0.78	343.5	-3.4	.73	32.5	.0	1.09	4-8950.0			
4-8960.0	71.1	0	1.00	249.6	-22.1	90.2	13	1.57	361.0	0.8	0.72	359.4	-3.3	.73	49.3	.0	1.03	4-8960.0			
4-8970.0	81.3	0	1.00	260.5	-23.2	95.1	15	1.58	362.6	2.8	0.67	31.3	-3.0	.73	64.2	.0	0.96	4-8970.0			
4-8980.0	91.5	0	1.00	271.6	-23.4	99.9	16	1.59	365.0	4.7	0.64	31.2	-2.4	.72	80.2	.0	0.99	4-8980.0			
4-8990.0	101.7	0	1.00	282.7	-22.9	104.6	18	1.61	35.0	6.6	0.63	47.3	-1.7	.72	96.2	.0	0.81	4-8990.0			
4-9000.0	111.8	0	1.00	293.6	-21.7	109.3	19	1.62	19.3	8.4	0.64	63.3	-1.0	.72	112.3	.0	0.74	4-9000.0			
4-9010.0	122.0	0	1.00	304.3	-19.7	113.9	21	1.62	23.7	10.1	0.67	79.4	-2	.72	128.4	.0	0.67	4-9010.0			
4-9020.0	132.2	0	1.00	314.7	-17.1	118.5	23	1.63	26.0	11.8	0.72	95.8	1.1	.72	144.6	.0	0.59	4-9020.0			
4-9030.0	142.3	0	1.00	324.7	-14.1	123.0	25	1.64	32.3	13.4	0.78	111.8	2.0	.72	160.8	.0	0.52	4-9030.0			
4-9040.0	152.4	0	1.00	334.4	-10.6	127.5	26	1.65	36.7	14.9	0.86	120.0	2.7	.72	177.0	.0	0.45	4-9040.0			
4-9050.0	162.5	0	1.00	343.8	-6.9	132.0	28	1.65	41.1	16.3	0.94	144.3	3.1	.72	193.3	.0	0.38	4-9050.0			
4-9060.0	172.5	0	1.00	353.1	-3.0	136.4	30	1.66	44.9	17.6	1.04	160.5	3.4	.72	209.5	.0	0.33	4-9060.0			
4-9070.0	182.4	0	1.00	362.2	1.0	140.8	32	1.66	49.9	18.8	1.13	176.7	3.3	.72	225.7	.0	0.29	4-9070.0			
4-9080.0	192.3	0	1.00	371.3	4.9	145.2	34	1.66	54.5	19.9	1.23	192.9	3.0	.72	241.9	.0	0.28	4-9080.0			
4-9090.0	202.1	0	1.00	380.5	6.6	149.6	36	1.67	59.0	20.9	1.32	209.0	2.5	.72	257.9	.0	0.30	4-9090.0			
4-9100.0	211.9	0	1.01	29.7	12.1	153.9	1	1.67	63.6	21.7	1.42	225.0	1.8	.72	274.0	0	0.34	4-9100.0			
4-9110.0	221.6	0	1.01	39.2	15.3	158.3	3	1.67	68.2	22.5	1.51	241.0	1.9	.72	290.0	0	0.40	4-9110.0			
4-9120.0	231.3	0	1.01	48.9	18.1	162.7	5	1.68	72.9	23.0	1.60	256.9	2.0	.72	305.9	0	0.47	4-9120.0			
4-9130.0	240.9	0	1.01	58.6	20.4	167.0	7	1.68	77.7	23.5	1.69	272.7	-1.0	.73	321.8	0	0.55	4-9130.0			
4-9140.0	250.5	0	1.01	68.9	22.0	171.4	9	1.68	82.5	23.8	1.78	288.6	-1.6	.73	337.6	0	0.63	4-9140.0			
4-9150.0	260.1	0	1.02	79.2	23.1	175.8	11	1.66	87.3	24.0	1.85	304.4	-2.5	.73	353.4	0	0.71	4-9150.0			
4-9160.0	269.7	0	1.02	89.6	23.4	180.3	13	1.65	92.1	24.0	1.93	320.2	-3.0	.73	9.2	0	0.79	4-9160.0			
4-9170.0	279.2	0	1.02	100.0	23.1	184.7	15	1.64	97.0	23.8	2.00	336.0	-3.3	.73	25.0	0	0.77	4-9170.0			
4-9180.0	288.7	0	1.02	110.3	22.1	189.2	17	1.64	101.9	23.5	2.06	351.9	-3.4	.73	40.9	0	0.75	4-9180.0			
4-9190.0	298.3	0	1.02	120.4	20.5	193.8	19	1.63	106.8	23.1	2.13	376.7	-3.2	.73	56.7	0	1.02	4-9190.0			
4-9200.0	307.8	0	1.02	130.2	18.3	198.4	21	1.62	111.0	22.5	2.10	23.7	-2.7	.72	72.7	0	0.10	4-9200.0			
4-9210.0	317.4	0	1.01	139.0	15.6	203.0	23	1.61	116.7	21.7	2.23	39.7	-2.0	.72	88.7	0	0.16	4-9210.0			
4-9220.0	327.0	0	1.01	149.2	12.5	207.7	25	1.60	121.6	20.7	2.20	55.6	-1.8	.72	104.7	0	0.13	4-9220.0			
4-9230.0	336.7	0	1.01	158.4	9.1	212.4	27	1.59	126.6	19.7	2.31	71.0	-1.3	.72	120.8	0	0.13	4-9230.0			
4-9240.0	346.3	0	1.01	167.4	5.4	217.3	29	1.59	131.5	16.4	2.35	88.0	0.7	.72	137.0	0	0.13	4-9240.0			
4-9250.0	356.1	0	1.00	176.4	1.6	222.1	31	1.57	136.4	17.1	2.30	104.1	1.0	.72	153.2	0	0.14	4-9250.0			
4-9260.0	365.9	0	1.00	185.4	-2.3	227.1	33	1.58	141.3	15.5	2.40	120.4	2.4	.72	169.4	0	0.14	4-9260.0			
4-9270.0	375.7	0	1.00	194.5	-6.2	232.1	35	1.54	146.3	13.9	2.42	136.6	2.9	.72	185.6	0	0.15	4-9270.0			
4-9280.0	385.6	0	1.00	203.8	-9.9	237.3	37	1.53	151.2	12.1	2.44	152.9	3.3	.72	201.9	0	0.14	4-9280.0			
4-9290.0	395.0	0	1.00	213.9	-15.7	238.7	39	1.49	171.2	9.3	2.45	217.5	2.1	.72	226.5	0	0.16	4-9290.0			
4-9300.0	405.6	0	1.																		

TABLE 2-5 (CONT.)

1 FEB 95

1 FEB 95

JULIAN DATE	EARTH					MARS						VENUS						JULIAN DATE
	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	PLAN LONG	PLAN LAT	SUN R	SUN RA	SUN DECL	COM DIST	
4-9750.0	131.7	.0	.99	314.1	-17.3	137.7	1.8	1.66	46.8	18.0	.69	186.3	3.2	.72	235.2	.0	.82	4-9750.0
4-9760.0	141.8	.0	.99	324.2	-14.2	142.1	1.8	1.66	51.3	19.1	.68	202.4	2.7	.72	251.4	.0	.89	4-9760.0
4-9770.0	151.9	.0	.99	333.9	-10.8	146.5	1.8	1.66	55.8	20.2	.69	218.5	2.1	.72	267.4	.0	.97	4-9770.0
4-9780.0	161.9	.0	.99	343.4	-7.1	150.9	1.8	1.67	60.4	21.1	.72	234.5	1.3	.72	283.4	.0	1.04	4-9780.0
4-9790.0	172.0	.0	.99	352.6	-3.2	155.2	1.8	1.67	65.0	22.0	.77	250.4	.4	.73	299.4	.0	1.11	4-9790.0
4-9800.0	181.9	.0	1.00	1.7	.8	159.6	1.7	1.67	69.7	22.6	.83	266.2	-.6	.73	315.3	.0	1.17	4-9800.0
4-9810.0	191.8	.0	1.00	10.8	4.7	164.0	1.7	1.66	74.4	23.2	.91	282.1	-1.5	.73	331.1	.0	1.24	4-9810.0
4-9820.0	201.6	.0	1.00	20.0	8.4	168.4	1.6	1.66	79.1	23.6	.99	297.9	-2.3	.73	346.9	.0	1.30	4-9820.0
4-9830.0	211.4	.0	1.01	29.3	12.0	172.8	1.5	1.66	83.9	23.9	1.08	313.7	-2.9	.73	2.7	.0	1.36	4-9830.0
4-9840.0	221.1	.0	1.01	38.7	15.2	177.2	1.5	1.65	88.7	24.0	1.16	329.5	-3.2	.73	18.5	.0	1.42	4-9840.0
4-9850.0	230.8	.0	1.01	46.4	18.0	181.6	1.4	1.65	93.6	23.9	1.25	345.4	-3.4	.73	34.4	.0	1.47	4-9850.0
4-9860.0	240.4	.0	1.01	58.3	20.3	186.1	1.3	1.64	98.5	23.8	1.34	1.3	.73	50.2	.0	1.52	4-9860.0	
4-9870.0	250.0	.0	1.01	68.4	22.0	190.6	1.2	1.64	103.4	23.4	1.42	17.2	-2.9	.73	66.1	.0	1.56	4-9870.0
4-9880.0	259.6	.0	1.02	78.7	23.0	195.2	1.0	1.63	108.3	22.9	1.50	33.2	-2.3	.72	82.1	.0	1.60	4-9880.0
4-9890.0	269.2	.0	1.02	89.1	23.4	199.8	.9	1.62	113.2	22.2	1.58	49.2	-1.6	.72	98.1	.0	1.64	4-9890.0
4-9900.0	278.7	.0	1.02	99.5	23.2	204.4	.8	1.61	118.2	21.4	1.65	65.2	-.7	.72	114.2	.0	1.67	4-9900.0
4-9910.0	288.2	.0	1.02	109.6	22.2	209.1	.6	1.60	123.1	20.4	1.73	81.3	.3	.72	130.3	.0	1.69	4-9910.0
4-9920.0	297.8	.0	1.02	119.9	20.6	213.9	.5	1.59	128.0	19.3	1.79	97.5	1.2	.72	146.5	.0	1.71	4-9920.0
4-9930.0	307.3	.0	1.02	129.7	18.4	218.7	.3	1.58	133.0	18.0	1.85	113.7	2.1	.72	162.7	.0	1.72	4-9930.0
4-9940.0	316.9	.0	1.01	139.4	15.8	223.6	.2	1.58	137.9	16.6	1.91	129.9	2.7	.72	179.0	.0	1.73	4-9940.0
4-9950.0	326.5	.0	1.01	148.7	12.7	228.6	-.0	1.55	148.6	15.0	1.97	146.2	3.2	.72	195.2	.0	1.73	4-9950.0
4-9960.0	336.2	.0	1.01	157.9	9.3	233.7	-.1	1.54	147.7	13.4	2.02	162.4	3.4	.72	211.4	.0	1.73	4-9960.0
4-9970.0	345.8	.0	1.01	167.0	5.6	238.0	-.3	1.53	152.7	11.5	2.06	178.7	3.3	.72	227.6	.0	1.72	4-9970.0
4-9980.0	355.6	.0	1.00	175.9	1.8	244.1	-.5	1.51	157.6	9.6	2.10	194.8	3.0	.72	243.8	.0	1.70	4-9980.0
4-9990.0	365.4	.0	1.00	184.9	-2.1	249.4	-.6	1.50	162.6	7.6	2.14	210.9	2.4	.72	259.9	.0	1.68	4-9990.0
5- .0	15.2	.0	1.00	194.0	-6.0	254.8	-.8	1.49	167.7	5.4	2.17	227.0	1.7	.72	275.9	.0	1.66	5- .0
5- 10.0	25.1	.0	1.00	203.3	-9.7	260.4	-.0	1.47	172.7	3.2	2.20	242.9	1.8	.73	291.9	.0	1.63	5- 10.0
5- 20.0	35.1	.0	1.00	212.8	-13.2	266.0	-.1	1.46	177.9	-.9	2.23	256.8	1.1	.73	307.8	.0	1.60	5- 20.0
5- 30.0	45.1	.0	1.00	222.6	-16.4	271.7	-.2	1.45	183.1	-1.4	2.25	274.6	-1.1	.73	323.7	.0	1.56	5- 30.0
5- 40.0	55.2	.0	1.00	232.6	-19.1	277.5	-.4	1.44	180.4	-3.7	2.27	290.4	-1.9	.73	339.5	.0	1.53	5- 40.0
5- 50.0	65.3	.0	1.00	243.4	-21.2	283.4	-.5	1.43	193.8	-6.1	2.29	306.3	-2.6	.73	355.3	.0	1.48	5- 50.0
5- 60.0	75.4	.0	1.00	254.2	-22.7	289.4	-.6	1.42	199.4	-8.4	2.30	322.1	-3.1	.73	311.1	.0	1.44	5- 60.0
5- 70.0	85.6	.0	1.00	265.2	-23.4	295.4	-.7	1.41	205.1	-10.7	2.32	337.9	-3.4	.73	26.9	.0	1.39	5- 70.0
5- 80.0	95.8	.0	1.00	276.3	-23.3	301.6	-.8	1.40	210.9	-12.9	2.33	353.8	-3.4	.73	42.8	.0	1.34	5- 80.0
5- 90.0	106.0	.0	1.00	287.3	-22.5	307.8	-.8	1.39	216.9	-15.0	2.34	9.7	-3.1	.73	58.7	.0	1.28	5- 90.0
5- 100.0	116.2	.0	1.00	298.2	-20.9	314.0	-.8	1.39	223.1	-16.9	2.35	25.6	-2.6	.72	74.6	.0	1.23	5- 100.0
5- 110.0	126.3	.0	1.00	308.7	-16.7	320.3	-.8	1.39	229.5	-16.7	2.35	41.6	-1.9	.72	90.6	.0	1.17	5- 110.0
5- 120.0	136.5	.0	1.00	318.9	-15.9	326.6	-.8	1.38	236.0	-20.2	2.36	57.7	-1.1	.72	106.6	.0	1.10	5- 120.0
5- 130.0	146.6	.0	1.00	328.8	-12.7	333.0	-.8	1.38	242.6	-21.6	2.37	73.8	-2.2	.72	122.8	.0	1.04	5- 130.0
5- 140.0	156.7	.0	1.00	338.4	-9.1	339.3	-.7	1.38	249.4	-22.6	2.37	89.9	-.8	.72	138.9	.0	0.97	5- 140.0
5- 150.0	166.7	.0	1.00	347.8	-5.3	345.7	-.7	1.38	256.2	-23.4	2.38	106.1	1.7	.72	155.1	.0	.90	5- 150.0
5- 160.0	176.7	.0	1.00	357.0	-1.3	352.0	-.6	1.39	261.1	-23.6	2.38	203.4	2.7	.72	223.3	.0	0.82	5- 160.0
5- 170.0	186.6	.0	1.00	6.1	2.6	358.3	-.3	1.39	269.9	-24.0	2.38	130.6	3.0	.72	187.6	.0	0.74	5- 170.0
5- 180.0	196.5	.0	1.00	15.2	6.5	4.5	-.3	1.40	276.6	-23.6	154.8	3.3	.72	203.8	.0	0.67	5- 180.0	
5- 190.0	206.3	.0	1.00	24.4	10.1	10.7	-.2	1.40	283.5	-23.4	2.39	171.0	3.4	.72	220.0	.0	0.59	5- 190.0
5- 200.0	216.0	.0	1.01	33.7	13.5	16.6	-.1	1.41	290.1	-22.7	2.39	187.2	3.2	.72	236.2	.0	0.51	5- 200.0
5- 210.0	225.7	.0	1.01	43.3	16.6	22.8	-.8	1.42	295.6	-21.7	2.38	203.4	2.7	.72	223.3	.0	0.44	5- 210.0
5- 220.0	235.4	.0	1.01	53.0	19.1	26.8	-.6	1.43	302.8	-20.5	2.38	219.4	2.0	.72	268.4	.0	0.37	5- 220.0
5- 230.0	245.0	.0	1.01	63.1	21.1	34.7	-.5	1.44	308.6	-19.1	2.37	235.4	1.2	.72	284.4	.0	0.32	5- 230.0
5- 240.0	254.6	.0	1.01	73.3	22.6	40.4	-.3	1.45	314.7	-17.5	2.36	251.3	-.3	.73	300.3	.0	0.29	5- 240.0
5- 250.0	264.1	.0	1.02	83.6	23.3	46.1	-.1	1.47	320.4	-15.8	2.35	287.2	-.6	.73	316.2	.0	0.29	5- 250.0
5- 260.0	273.7	.0	1.02	94.0	23.4	51.7	-.1	1.48	329.5	-14.0	2.33	283.0	-1.5	.73	332.0	.0	0.32	5- 260.0
5- 270.0	283.2	.0	1.02	104.4	22.8	57.2	-.3	1.49	331.1	-12.1	2.32	298.8	-2.3	.73	347.9	.0	0.37	5- 270.0
5- 280.0	292.8	.0	1.02	114.6	21.5	62.6	-.4	1.50	336.3	-10.1	2.32	291.4	-2.9	.73	3.7	.0	0.44	5- 280.0
5- 290.0	302.3	.0	1.02	124.6	19.7	67.9	-.6	1.51	341.3	-8.1	2.26	330.5	-3.3	.73	19.5	.0	0.51	5- 290.0
5- 300.0	311.9	.0	1.01	134.3	17.2	73.1	-.7	1.53	346.1	-6.1	2.23	346.3	-3.4	.73	35.3	.0	0.59	5- 300.0
5- 310.0	321.5	.0	1.01	143.8	14.4	78.3	-.9	1.54	350.8	-4.1	2.19	2.2	-3.3	.73	51.2	.0	0.66	5- 310.0
5- 320.0	331.1	.0	1.01	153.1	11.1	83.3	-.0	1.55	353.4	-2.0	2.15	18.1	-2.9	.73	67.1	.0	0.74	5- 320.0
5- 330.0	340.7	.0	1.01	162.2	7.5	88.3	1.2	1.56	360.0	-0.0	2.10	34.1	-2.3	.72	83.1	.0	0.82	5- 330.0
5- 340.0	350.5	.0	1.01	171.2	3.8	93.2	1.3	1.58	4.5	2.0	2.05	50.1	-1.5	.72	99.1	.0	0.89	5- 340.0
5- 350.0																		

TABLE 2-5 (CONT.)

17 DEC 97

17 DEC 97

JULIAN DATE	EARTH						MARS						VENUS						JULIAN DATE
	PLAN LONG	PLAN LAT	SUN RA	SUN DECL	PLAN LONG	PLAN LAT	SUN RA	SUN DECL	SUN COM DIST	PLAN LONG	PLAN LAT	SUN RA	SUN DECL	SUN COM DIST	PLAN LONG	PLAN LAT	SUN RA	SUN DECL	
5- 600.0	85.1	.0	.98	264.6	-23.4	322.2	-1.8	1.38	231.4	-19.2	2.09	67.2	-.5	.72	116.1	.0	.37	5- 600.0	
5- 610.0	95.3	.0	.98	275.7	-23.3	328.3	-1.8	1.38	238.0	-20.7	2.12	83.5	.4	.72	132.3	.0	.52	5- 610.0	
5- 620.0	105.4	.0	.98	286.8	-22.6	334.9	-1.8	1.38	244.6	-21.9	2.15	99.4	1.3	.72	148.5	.0	.28	5- 620.0	
5- 630.0	115.6	.0	.98	297.6	-21.0	341.4	-1.7	1.38	251.4	-22.9	2.19	115.7	2.2	.72	164.7	.0	.27	5- 630.0	
5- 640.0	125.8	.0	.98	308.2	-18.8	347.6	-1.6	1.38	258.3	-23.5	2.22	131.9	2.8	.72	180.9	.0	.28	5- 640.0	
5- 650.0	136.0	.0	.98	318.4	-16.1	353.9	-1.5	1.39	265.1	-23.9	2.25	148.1	3.2	.72	197.2	.0	.32	5- 650.0	
5- 660.0	146.1	.0	.98	328.3	-12.8	362.0	-1.4	1.39	272.0	-24.0	2.28	164.4	3.4	.72	213.4	.0	.38	5- 660.0	
5- 670.0	156.2	.0	.98	337.9	-9.3	364.2	-1.3	1.40	278.6	-23.0	2.31	180.6	3.3	.72	229.6	.0	.45	5- 670.0	
5- 680.0	166.2	.0	.98	347.3	-5.5	372.5	-1.1	1.41	285.5	-23.2	2.34	196.8	2.9	.72	245.7	.0	.52	5- 680.0	
5- 690.0	176.2	.0	1.00	356.5	-1.5	374.6	-0.9	1.41	292.1	-22.4	2.36	212.9	2.3	.72	261.0	.0	.60	5- 690.0	
5- 700.0	186.1	.0	1.00	365.6	2.4	24.7	-.8	1.42	298.4	-21.4	2.39	228.9	1.6	.72	277.8	.0	.68	5- 700.0	
5- 710.0	196.3	.0	1.00	14.7	6.3	30.6	-.6	1.43	304.6	-20.1	2.42	248.0	.7	.73	293.8	.0	.76	5- 710.0	
5- 720.0	205.8	.0	1.00	23.9	10.0	36.4	-.4	1.45	310.6	-18.7	2.44	260.7	-.3	.73	309.7	.0	.83	5- 720.0	
5- 730.0	215.5	.0	1.01	33.2	13.4	42.2	-.2	1.46	316.4	-17.0	2.46	276.5	-1.2	.73	325.6	.0	.91	5- 730.0	
5- 740.0	225.2	.0	1.01	42.8	16.4	47.8	0	1.47	322.1	-15.3	2.48	292.3	-2.0	.73	341.4	.0	.99	5- 740.0	
5- 750.0	234.9	.0	1.01	52.5	19.0	53.4	.1	1.48	327.5	-13.5	2.49	308.1	-2.7	.73	357.2	.0	1.06	5- 750.0	
5- 760.0	244.5	.0	1.01	62.5	21.1	58.9	.3	1.49	332.7	-11.5	2.50	324.0	-3.1	.73	373.0	.0	1.13	5- 760.0	
5- 770.0	254.1	.0	1.01	72.7	22.5	64.2	.5	1.51	337.8	-9.5	2.51	339.8	-3.4	.73	386.8	.0	1.20	5- 770.0	
5- 780.0	263.7	.0	1.02	83.1	23.3	69.5	.6	1.52	342.7	-7.5	2.52	355.7	-3.3	.73	44.7	.0	1.27	5- 780.0	
5- 790.0	273.2	.0	1.02	93.5	23.4	74.7	.8	1.53	347.5	-5.5	2.52	11.6	-3.1	.73	60.6	.0	1.33	5- 790.0	
5- 800.0	282.7	.0	1.02	103.6	22.8	79.8	9	1.55	352.2	-3.4	2.51	27.6	-2.6	.72	76.5	.0	1.39	5- 800.0	
5- 810.0	292.3	.0	1.02	114.1	21.6	84.8	1.1	1.56	356.8	-1.4	2.51	43.6	-1.8	.72	92.5	.0	1.45	5- 810.0	
5- 820.0	301.8	.0	1.02	124.1	19.8	89.8	1.2	1.57	1.5	.6	2.49	59.6	-1.0	.72	108.6	.0	1.50	5- 820.0	
5- 830.0	311.4	.0	1.01	133.8	17.4	94.6	1.3	1.58	5.8	2.6	2.47	75.7	0	.72	124.7	.0	1.54	5- 830.0	
5- 840.0	321.0	.0	1.01	143.4	14.5	99.4	1.4	1.59	10.2	4.5	2.45	91.6	.9	.72	140.9	.0	1.58	5- 840.0	
5- 850.0	330.6	.0	1.01	152.6	11.3	104.2	1.5	1.60	14.6	6.4	2.42	100.0	1.8	.72	157.1	.0	1.62	5- 850.0	
5- 860.0	340.2	.0	1.01	161.8	7.7	109.9	1.6	1.61	18.9	8.2	2.38	124.3	2.5	.72	173.3	.0	1.64	5- 860.0	
5- 870.0	350.0	.0	1.01	170.8	4.0	115.5	1.7	1.62	23.2	10.0	2.33	140.5	3.1	.72	189.5	.0	1.67	5- 870.0	
5- 880.0	359.7	.0	1.00	179.7	-.1	118.1	1.7	1.63	27.6	11.6	2.29	156.8	3.3	.72	205.8	.0	1.69	5- 880.0	
5- 890.0	369.5	.0	1.00	188.8	12.8	122.6	1.8	1.64	31.9	13.2	2.23	173.0	3.4	.72	222.0	.0	1.70	5- 890.0	
5- 900.0	19.4	.0	1.00	197.9	-7.6	127.1	1.8	1.65	36.3	14.7	2.17	189.2	3.1	.72	236.1	.0	1.71	5- 900.0	
5- 910.0	29.3	.0	1.00	207.3	-11.2	131.5	1.8	1.65	40.7	16.2	2.10	203.3	2.6	.72	254.2	.0	1.72	5- 910.0	
5- 9120.0	39.3	.0	1.00	216.9	-14.6	138.0	1.8	1.66	45.1	17.5	2.03	221.3	1.9	.72	270.3	.0	1.71	5- 9120.0	
5- 9130.0	49.4	.0	1.00	226.9	-17.6	140.4	1.8	1.66	49.5	18.7	1.95	237.3	1.1	.72	286.3	.0	1.71	5- 9130.0	
5- 9140.0	59.4	.0	1.00	237.2	-20.0	144.8	1.8	1.66	54.0	19.8	1.86	253.2	2	.73	302.2	.0	1.70	5- 9140.0	
5- 9150.0	69.6	.0	1.00	197.9	-21.9	149.1	1.8	1.66	58.6	20.8	1.77	269.1	-.8	.73	318.1	.0	1.69	5- 9150.0	
5- 9160.0	79.7	.0	1.00	258.6	-23.1	153.5	1.8	1.67	63.2	21.7	1.68	284.9	-1.6	.73	333.9	.0	1.67	5- 9160.0	
5- 9170.0	89.9	.0	1.00	269.9	-23.4	157.9	1.8	1.67	67.8	22.4	1.59	300.7	-2.4	.73	349.8	.0	1.65	5- 9170.0	
5- 9180.0	100.1	.0	1.00	281.0	-23.1	162.2	1.7	1.66	72.5	23.0	1.49	316.5	-2.9	.73	35.6	.0	1.63	5- 9180.0	
5- 9190.0	110.3	.0	1.00	291.9	-21.9	166.6	1.6	1.66	77.2	23.5	1.39	332.4	-3.3	.73	21.4	.0	1.60	5- 9190.0	
5- 9200.0	120.5	.0	1.00	302.7	-20.1	171.0	1.6	1.66	82.0	23.8	1.28	348.2	-3.4	.73	37.2	.0	1.57	5- 9200.0	
5- 9210.0	130.6	.0	1.00	313.1	-17.6	175.4	1.5	1.66	86.8	24.0	1.18	41	-5.2	.73	53.1	.0	1.53	5- 9210.0	
5- 9220.0	140.6	.0	1.00	323.2	-14.6	179.9	1.4	1.65	91.7	24.0	1.08	20.1	-2.8	.73	69.0	.0	1.49	5- 9220.0	
5- 9230.0	150.9	.0	1.00	332.9	-11.2	184.3	1.3	1.64	96.5	23.8	.98	36.0	-2.2	.72	85.0	.0	1.45	5- 9230.0	
5- 9240.0	160.9	.0	1.00	342.4	-7.5	188.6	1.2	1.64	101.4	23.6	.89	52.1	-1.4	.72	101.0	.0	1.40	5- 9240.0	
5- 9250.0	170.9	.0	1.00	351.7	-3.6	193.3	1.1	1.63	106.4	23.1	.81	68.1	-.5	.72	117.1	.0	1.35	5- 9250.0	
5- 9260.0	180.9	.0	1.00	360.8	-.6	197.9	1.0	1.62	111.3	22.5	.73	84.2	5	.72	133.2	.0	1.30	5- 9260.0	
5- 9270.0	190.8	.0	1.00	37.9	4.3	202.6	-.8	1.61	116.2	21.8	.67	100.4	1.4	.72	149.4	.0	1.23	5- 9270.0	
5- 9280.0	200.6	.0	1.00	19.0	8.1	207.2	-.7	1.60	121.2	20.8	.62	116.6	2.2	.72	165.7	.0	1.17	5- 9280.0	
5- 9290.0	210.4	.0	1.00	28.3	11.6	212.0	-.5	1.59	126.1	19.8	.59	132.9	2.8	.72	181.9	.0	1.10	5- 9290.0	
5- 9300.0	220.1	.0	1.01	37.7	14.9	216.8	-.4	1.58	131.0	18.6	.58	149.1	3.2	.72	198.1	.0	1.03	5- 9300.0	
5- 9310.0	229.8	.0	1.01	47.4	17.7	221.7	-.2	1.57	135.9	17.2	.59	165.4	3.4	.72	214.4	.0	.96	5- 9310.0	
5- 9320.0	239.5	.0	1.01	57.3	20.0	226.6	-.1	1.56	140.9	15.7	.61	181.6	3.3	.72	230.5	.0	.88	5- 9320.0	
5- 9330.0	249.1	.0	1.01	67.4	21.8	231.7	-.1	1.54	145.6	14.0	.65	197.7	2.9	.72	246.7	.0	.80	5- 9330.0	
5- 9340.0	258.6	.0	1.02	77.6	23.0	236.8	-.2	1.53	150.7	12.3	.70	213.0	2.3	.72	262.8	.0	.72	5- 9340.0	
5- 9350.0	268.2	.0	1.02	88.0	23.4	242.0	-.4	1.52	155.7	10.4	.75	229.8	1.5	.72	278.6	.0	.64	5- 9350.0	
5- 9360.0	277.7	.0	1.02	98.4	23.3	247.3	-.6	1.51	160.7	8.4	.81	245.8	.6	.73	294.7	.0	.56	5- 9360.0	
5- 9370.0	287.3	.0	1.02	108.7	22.3	252.7	-.7	1.49	165.7	6.3	.87	261.6	-.3	.73	310.6	.0	.48	5- 9370.0	
5- 9380.0	296.8	.0	1.02	110.6	20.8	258.2	-.9	1.48	170.7	4.1	.93	277.5	-1.2	.73	326.5	.0	.41	5- 9380.0	
5- 9390.0	306.3	.0	1.02	128.7	18.7	263.7	-.1	1.47	175.8	1.9	1.00	293.3	-2.0	.73	342.3	.0	.35	5- 9390.0	
5- 9400.0	315.9	.0</td																	

Section 3

GRAPHICAL TRAJECTORY DATA

The round trip trajectory data for each mission opportunity are presented graphically in this section. The intended purpose of the graphical displays is to provide a means for rapidly locating mission windows of interest. Once the region of interest is known, one may turn to the tabular data, presented in subsequent sections, for more detailed information.

The graphical data included in this section consists of a set of three charts for each mission opportunity. One of the charts is termed a contour chart and is divided into two sections; the left half pertains to the Earth-to-Mars trajectory and the right half pertains to the return flight. The second chart is a total mission velocity plot which indicates the minimum incremental velocity required to perform the mission as a function of mission duration. The third chart presents the Earth entry speeds associated with these minimum mission velocity requirements. The three charts are placed together to facilitate their use in studying a given opportunity. The contour chart, the mission velocity plot, and the Earth entry speed chart are denoted parts A, B, and C, respectively, of the same figure, and there is one figure for each of the 16 mission opportunities. Preceding each set of three charts is a page of discussion pertaining to any unique or special features exhibited in the graphical data.

Unlike the case for direct transfers, multiple solutions of swingby trajectories frequently exist for a given date at Earth and date at Mars. Each solution, characterized by a unique Venus swingby date, belongs to a distinct family of solutions, and a contour chart could be prepared for each of the families. If these contour charts were to be plotted on the same graph, they would usually overlap and would be extremely difficult to understand and use. Only one family of solutions for each opportunity is shown on the contour charts. The selection of the particular family to be presented was based on such considerations as velocity requirements, departure window size, and mission duration. For the Category 3 swingby opportunities, the appropriate choice was obvious;

however the Category 5 opportunities frequently provided two or more competitive families and the ultimate choice was somewhat arbitrary. Thus, it is to be emphasized that the contour charts do not contain all the solutions of interest, and it may be of advantage to scan the tabular data for other available missions.

The contour charts, part A of each of the sets of figures, contain curves of constant hyperbolic excess speed at departure and arrival of Earth and Mars for the outbound leg on the left side and for the return leg on the right side. These contours are plotted on a grid of date at Earth along the abscissa and date at Mars along the ordinate. In addition, on the side pertaining to the swingby trajectory, contours of constant Venus passage date and passage distance are included. The speed contours for the direct legs possess the characteristic porkchop shape with the well-known "ridge" extending upwards and to the right, separating the Type 1 and Type 2 trajectories. Within the Category 3 opportunities, the contour charts for the swingby legs exhibit a considerable amount of similarity. Characteristically, the speed at Mars contours are oval shaped, the speed at Earth contours are nearly vertical lines, and the passage date contours are parabolic shaped. All Category 3 families of solutions chosen for presentation contained Type 2 trajectories between Earth and Venus and Type 1 trajectories between Venus and Mars. The Category 5 swingby contours do not possess the similarity among the opportunities to the extent noted with the Category 3 missions. Generally speaking, the departure windows of the Category 5 missions are smaller than those of Category 3.

As a point of interest, it may be noted that occasionally there exists multiple swingby solutions for given dates at Earth and Mars within a single family. Such situations may be recognized in the contour charts as the regions where the constant passage distance contours appear to intersect. VanderVeen¹⁰ has pointed out that such occurrences are more easily understood if one considers the situation depicted in three dimensions with the third dimension being swingby date. Then the contours form a surface which tends to fold back on itself, and the contours that appear to intersect when projected on a plane are seen to actually lie on different sides of the surface.

The mission velocity plots, part B of each set of figures, contain the minimum total mission velocity requirements as a function of mission duration for zero-, 30-, and 60-day stopover times. These velocities correspond to the particular family of solutions represented in the contour charts. For each mission duration, the velocity requirement shown is the minimum possible in the sense that no other combination of Earth departure date and Mars arrival date in the family will permit a smaller total velocity requirement subject to the constraint that the Venus passage distance must be 1.1 Venus radii or greater. Because one family of solutions generally does not contain the minimum mission velocities for all mission durations, missions will occasionally be found in the tabular data with total velocities less than that shown for a given mission duration on the mission velocity chart. Curves are presented for both propulsive braking (solid lines) and atmospheric braking (dashed lines) at Mars arrival. Mission velocities for propulsive braking are defined as the sum of Earth and Mars departure and Mars arrival velocity increments. Mission velocities for atmospheric braking are defined as the sum of Earth and Mars departure velocity increments. The velocity increments are predicated on impulsive thrust maneuvers at the planets assuming circular parking orbits of 485 and 500 kilometers altitude at Earth and Mars, respectively. The mission velocity curves generally exhibit cusps at some value of mission duration. The cusps occur at the transition from Type 1 to Type 2 trajectories on the direct leg. The Type 1 direct trajectories are associated with the short mission durations to the left of the cusps. The cusp itself does not represent a direct leg transfer of exactly 180 degrees. Type 1 trajectories do exist for longer mission durations (and Type 2 for shorter mission durations), but these do not yield minimum mission velocities.

The Earth entry speeds are presented in part C of each set of figures as a function of mission duration for both propulsive braking and aerodynamic braking at Mars. In most opportunities, the entry speeds are shown only for the 30-day stopover time because the variation of entry speed with stopover time is usually small. The inclusion of all three stopover times would often lead to difficulty in reading the figure. The entry speeds shown are those associated with the trajectories yielding the minimum total mission velocities as described in the preceding paragraph. The entry velocities are evaluated at an altitude of 120 km above the Earth's surface at the equator.

1975 INBOUND SWINGBY

The swingby trajectories during this opportunity are of Category 3. The family of solutions shown have Type 1 trajectories on the Mars-to-Venus leg and Type 2 trajectories on the Venus-to-Earth leg. This is the only family of solutions available for this opportunity within the date ranges investigated.

Except for the longer mission durations, the solutions that yield the minimum mission velocities of part B of this figure are generally unaffected by the constraint that the Venus passage distance be above 1.1 Venus radii. The exceptions are as follows:

	Stopover Time	Mission Durations
Propulsive Braking	0	560, 640, 680
	30	680
	60	680
Aerodynamic Braking	0	640, 680
	30	600, 640, 680
	60	600, 680

The Earth entry speeds associated with the zero- and 60-day stopover minimum velocity missions vary from those shown for the 30-day stopover by an amount that is larger than normal for Category 3 missions. Generally speaking, if the speeds for zero- and 60-day stopovers were to be plotted, they would lie about 1 km/sec above the corresponding propulsive and aero braking curves for 30-day stopovers.

MARS STOPOVER MISSION USING VENUS SWINGBYS

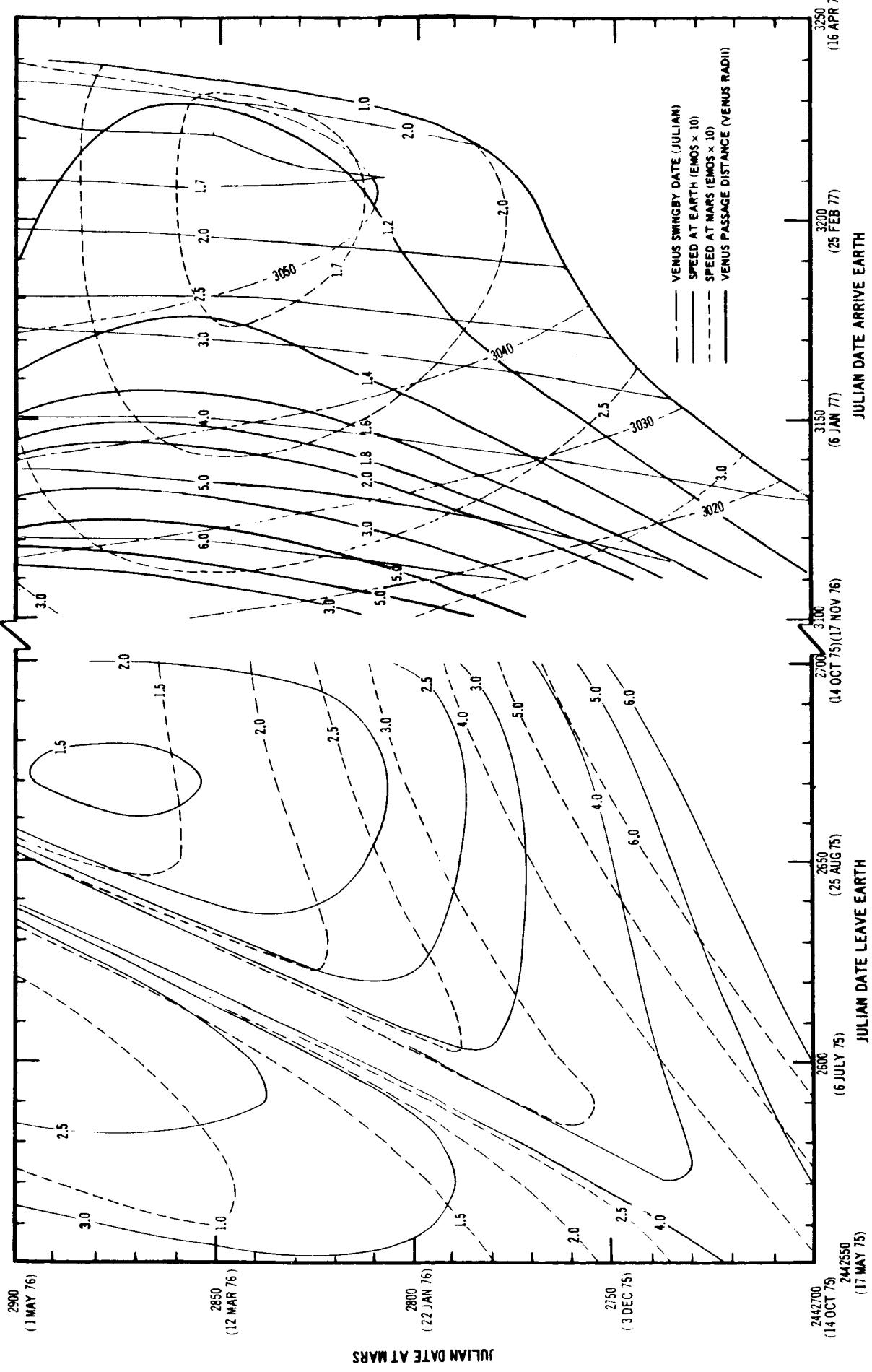


FIGURE 3-1A. 1975 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

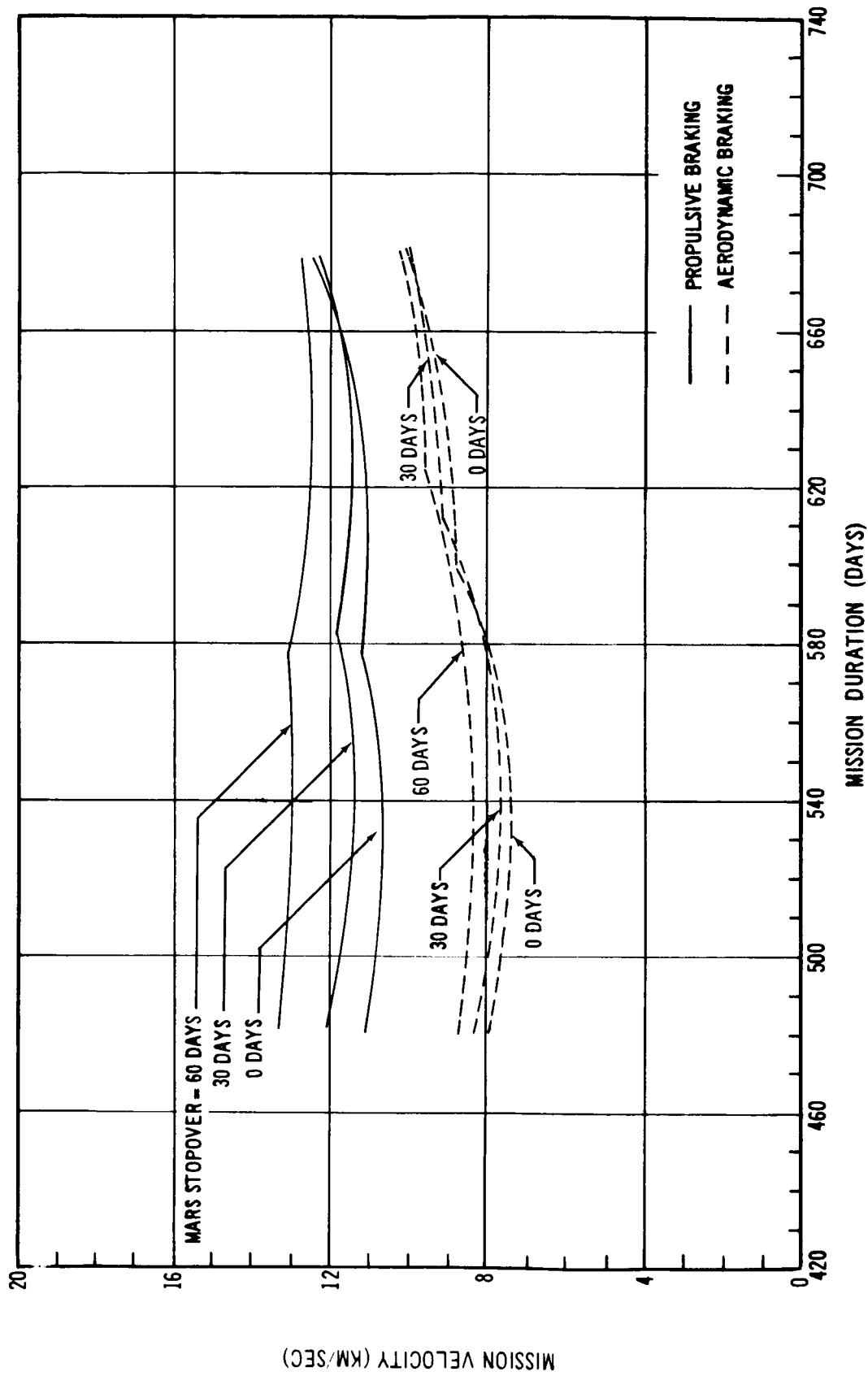


FIGURE 3-1B. 1975 INBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

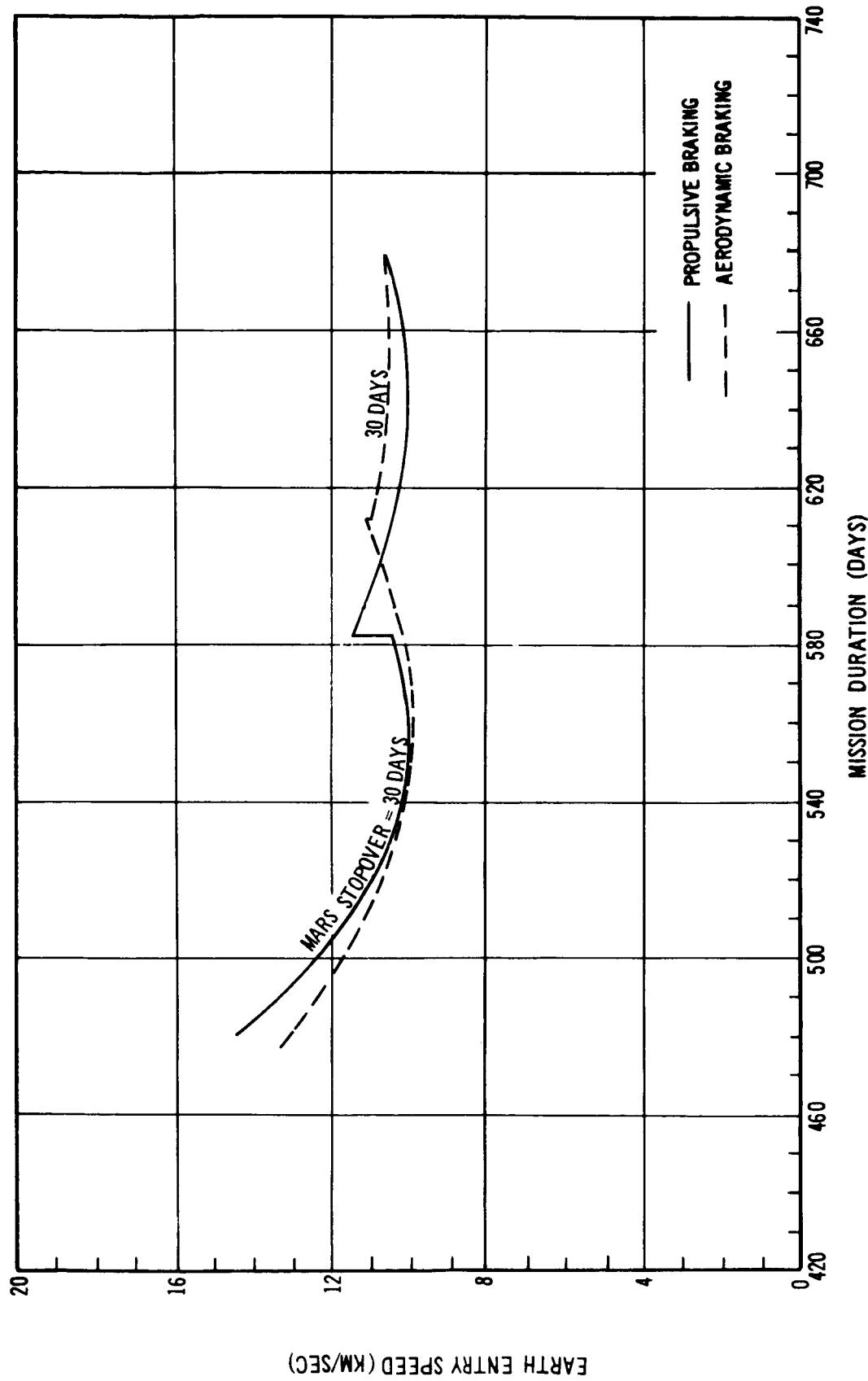


FIGURE 3-1C. 1975 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1978 OUTBOUND SWINGBY

This is a Category 5 swingby opportunity. Both the Earth-to-Venus and Venus-to-Mars legs for the family shown on the contour chart are Type 1 trajectories. This particular family presents an extremely small departure window within which the maximum passage distance just slightly exceeds 1.1 Venus radii. There is, in fact, only one grid point (because of the 10 day increments) within the family that satisfies the Venus passage distance constraint imposed in the mission velocity charts. Therefore, the one swingby solution is used for all trip times, and the shape of the mission velocity curves follow the behavior of the Mars departure velocity as a function of the return leg flight time holding Mars departure date fixed. Likewise, the Earth entry speed curves differ in appearance from those of all other opportunities because the Mars departure date remains fixed for each stopover time throughout all mission durations. The Earth entry speeds for propulsive and aero braking must be identical since the same return trajectory must be used for both cases.

There exist two other families of solutions within this opportunity that provide somewhat larger windows and competitive mission velocities but result in longer mission durations. One of these two families consists of a type 1/2* combination of trajectories on the swingby leg while the other family consists of a Type 2/1 combination. On the Earth departure date - Mars arrival date grid these families overlap and generally lie above and to the left of the family shown.

*This notation is the same as that employed in the tabular data. The trajectory types are given in the order in which the legs occur.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

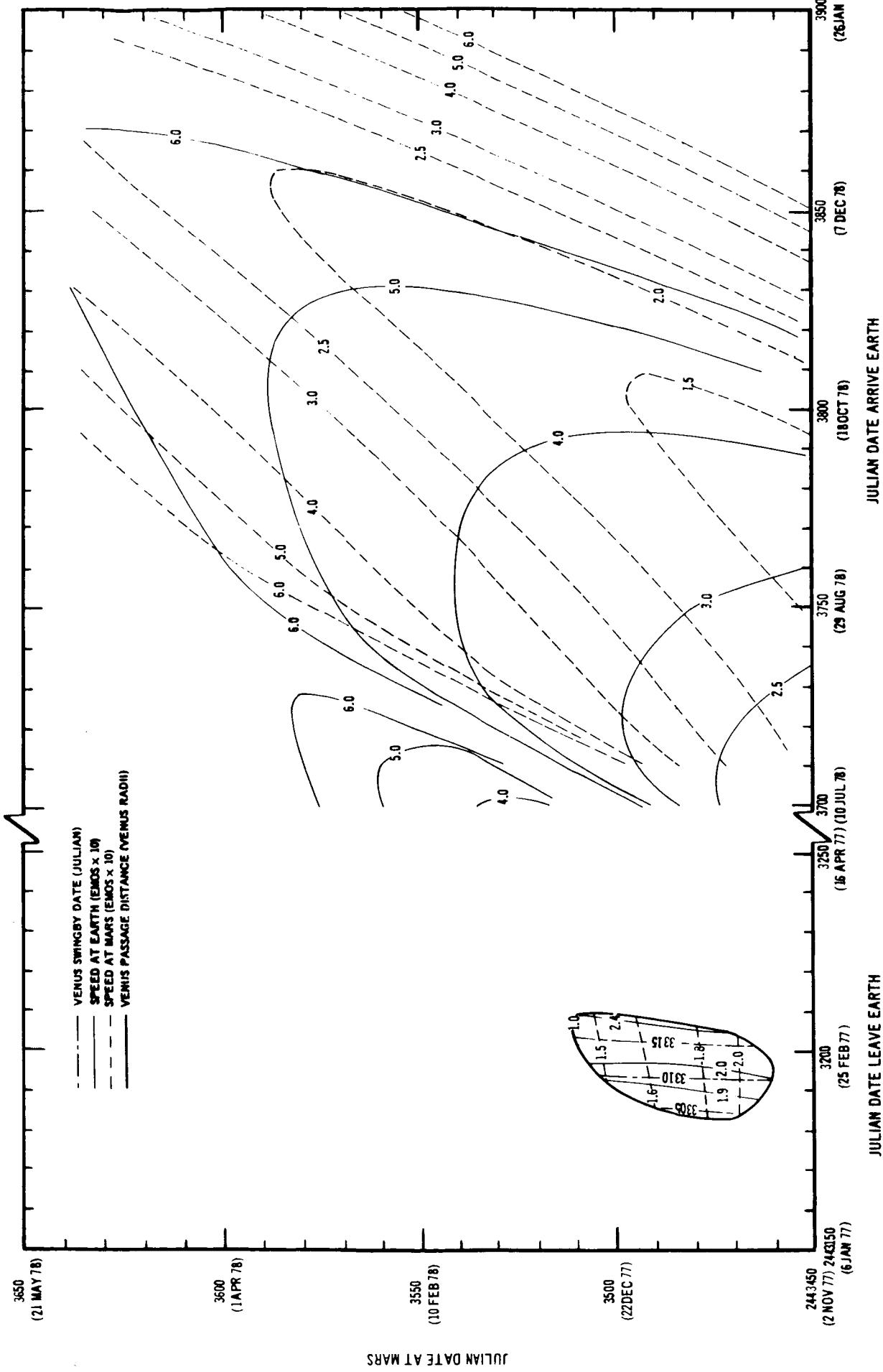


FIGURE 3-2A. 1978 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

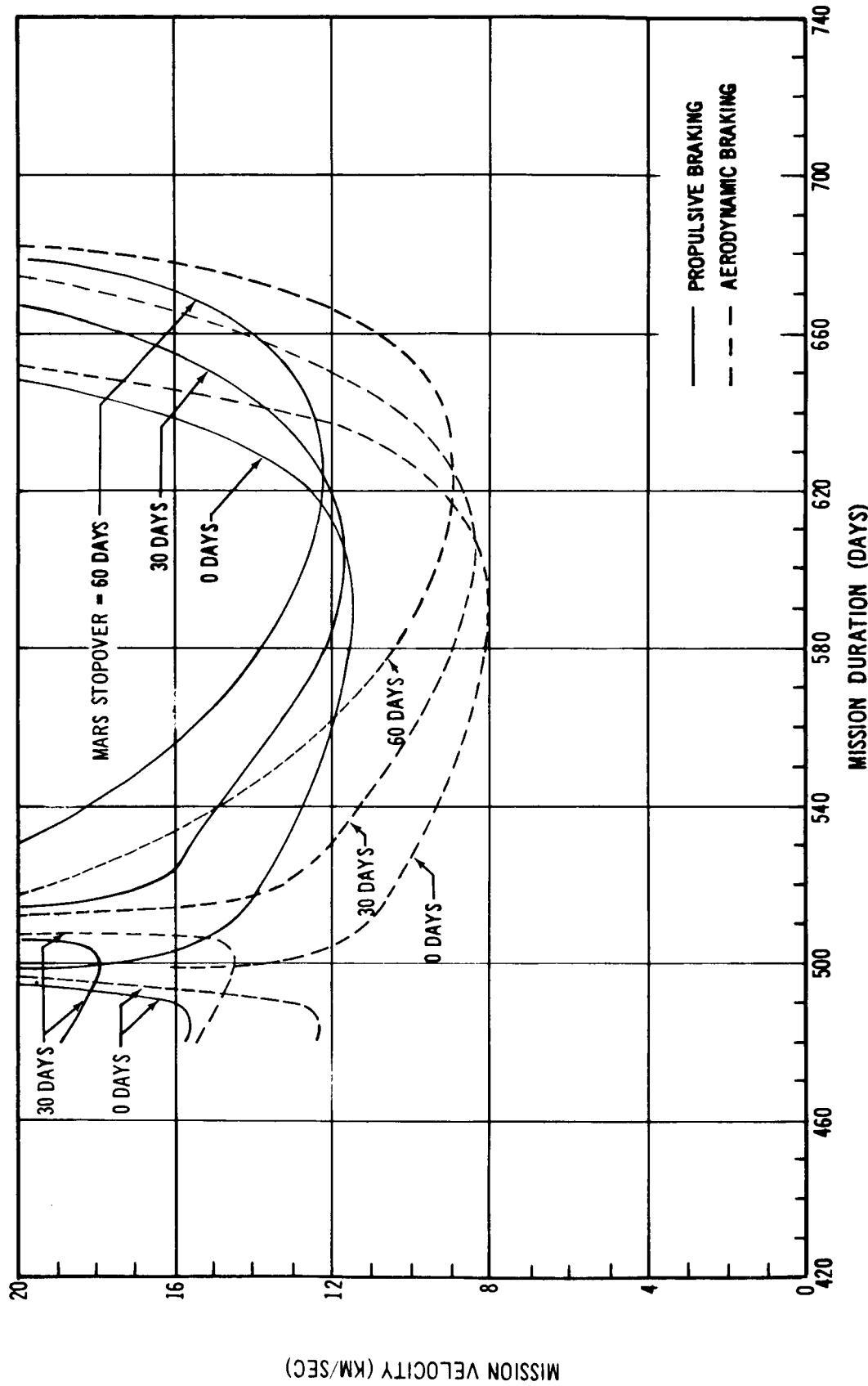


FIGURE 3-2B. 1978 OUTBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

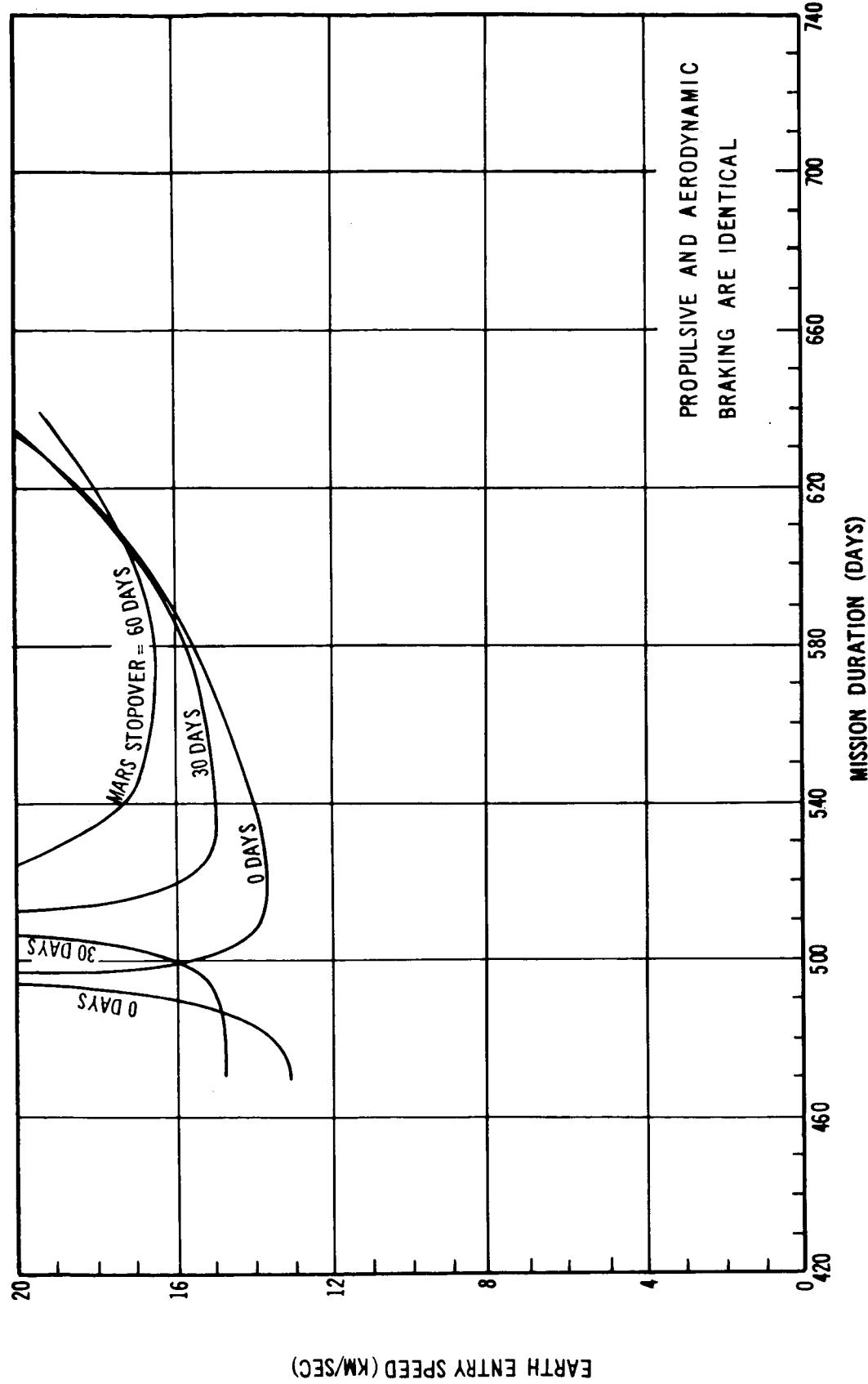


FIGURE 3-2C. 1978 OUTBOUND SWINGBY - EARTH ENTRY SPEEDS

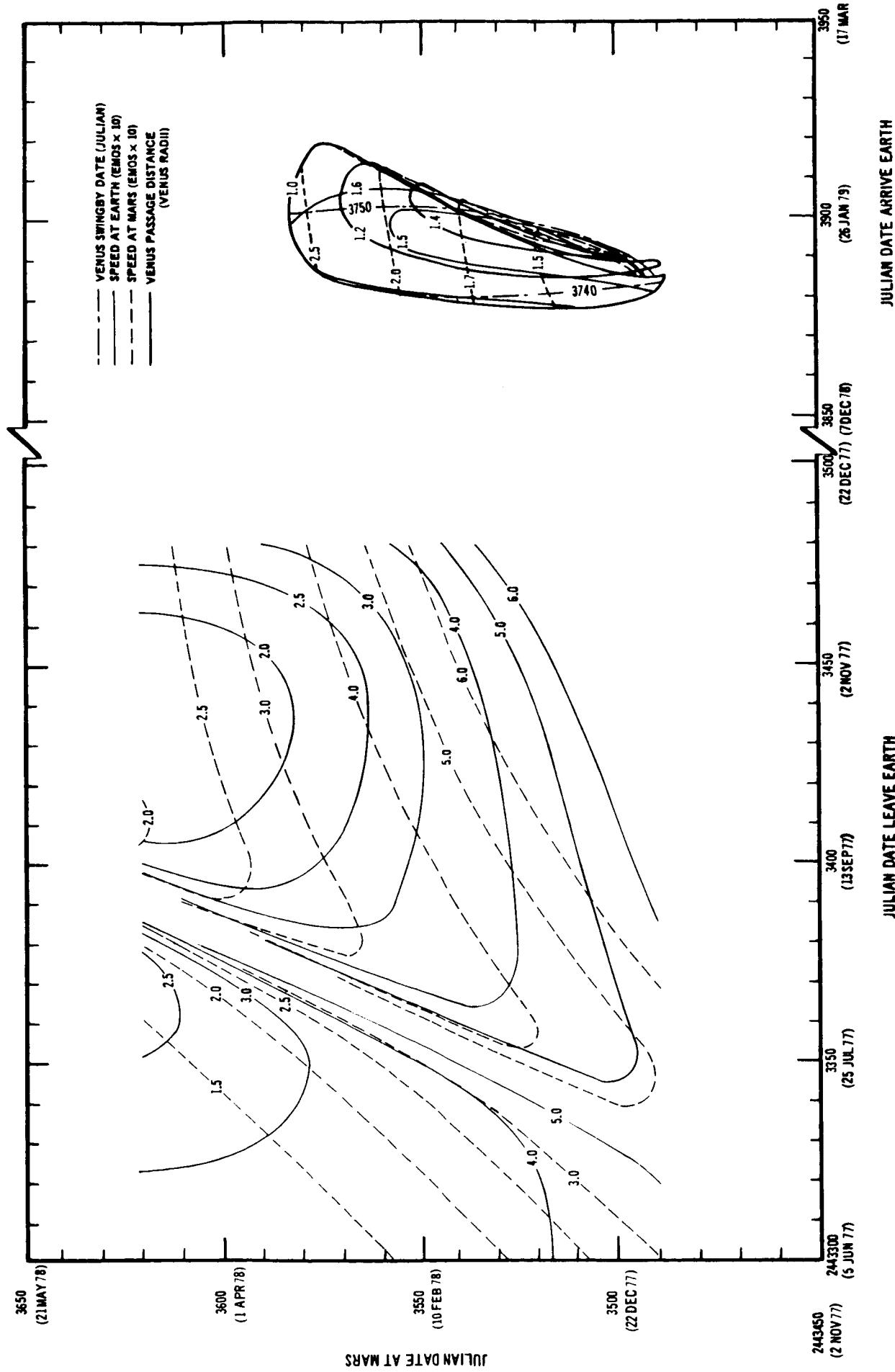
1978 INBOUND SWINGBY

This Category 5 family consists of a Type 1/2 combination of trajectories on the swingby leg. The family shown is one of two families contained in the tabular data with this combination. The two families may be distinguished in the tabular data by the differences in swingby date. Also included in the tabular data are missions representing the other three trajectory type combinations, i.e., 1/1, 2/1, and 2/2. All of these families require high mission velocities compared to other opportunities. The family shown in the contour chart exhibits the three-dimensional effect described earlier.

From the tabular data it appears that nearly all the missions resulting in the minimum mission velocities presented in Figure 3-3B lie very near either the passage distance constraint of 1.1 Venus radii or the right-hand edge of the surface. Because of the limited number of grid points available in the family, it is generally difficult to determine whether the minimum mission velocities represent stationary minima or boundary values. As a point of interest, the minimum velocity missions for the longest mission duration include direct legs at the boundaries of the data ranges investigated.

The Earth entry speeds associated with the minimum mission velocities are seen to be quite insensitive to mission duration. The entry speed is also very insensitive to stopover time as the data points for zero- and 60-day stopovers fall almost exactly on the curves shown.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS



JULIAN DATE LEAVE EARTH

JULIAN DATE ARRIVE EARTH

FIGURE 3-3A. 1978 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

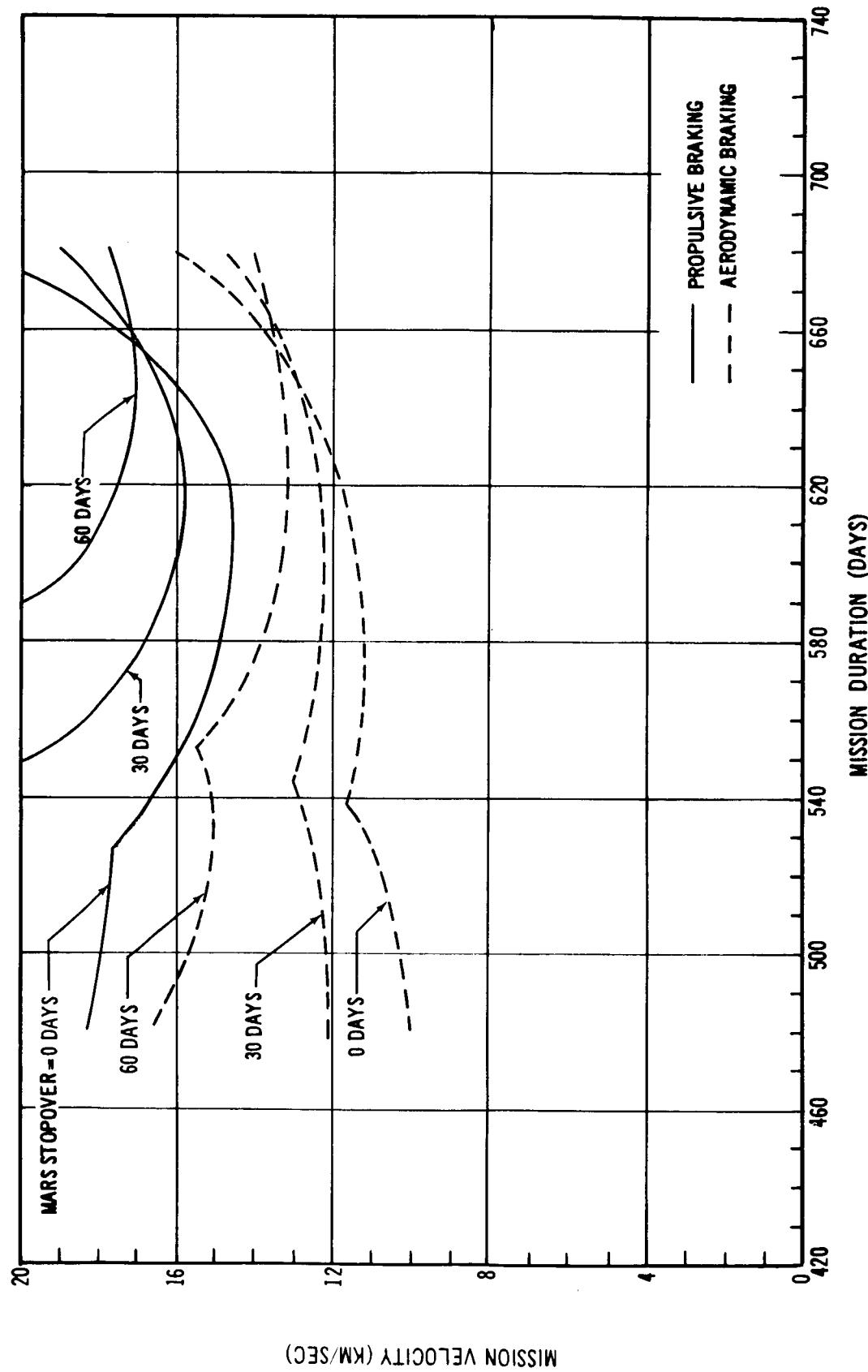


FIGURE 3-3B. 1978 INBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

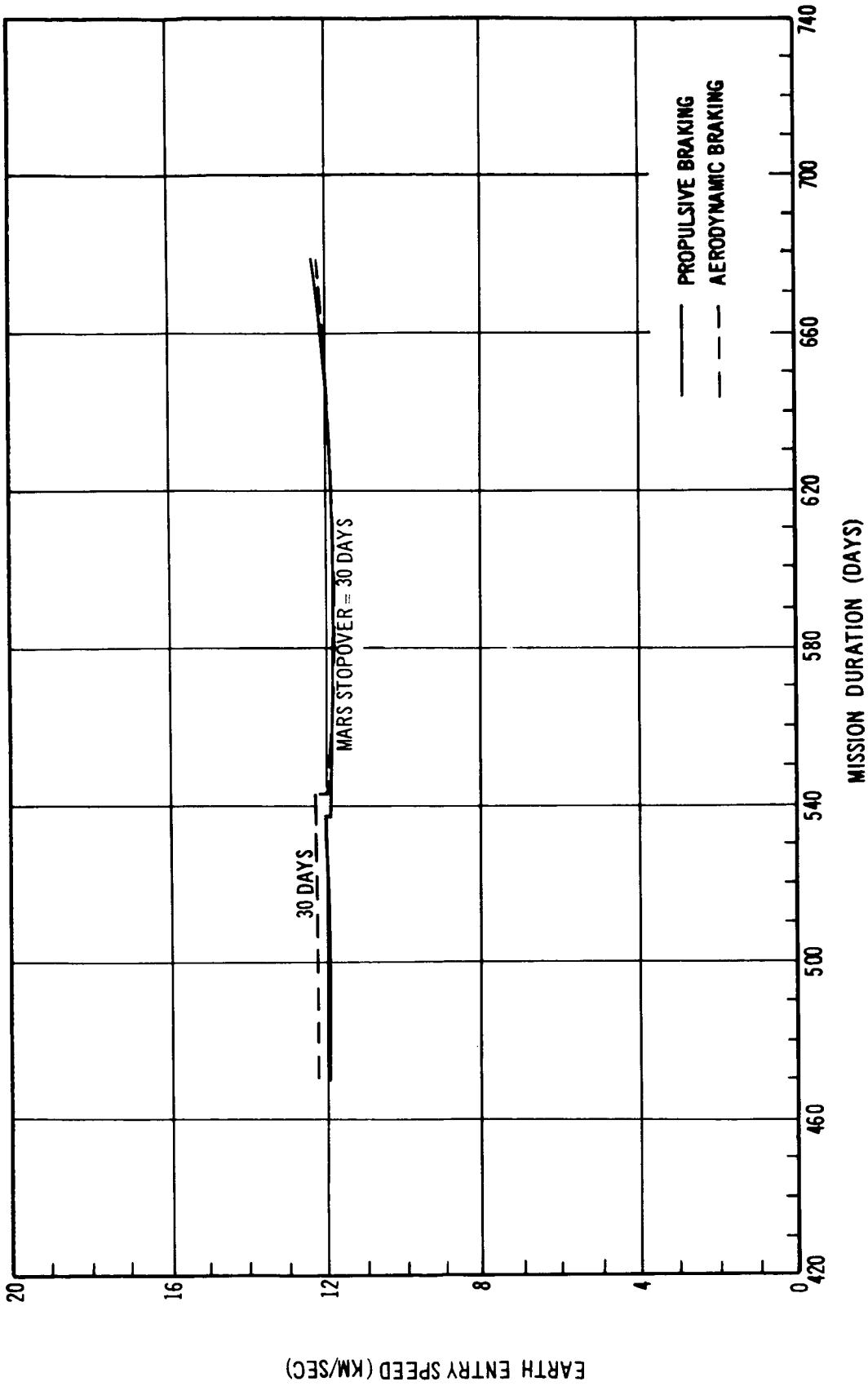


FIGURE 3-3C, 1978 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1980 OUTBOUND SWINGBY

The swingby trajectories during this opportunity are Category 3 trajectories. As noted previously, all Category 3 outbound swingbys have Type 2 trajectories on the Earth-to-Venus leg and Type 1 trajectories on the Venus-to-Mars leg. This is the only family of missions in the date ranges investigated.

In this opportunity, the minimum mission velocities for propulsive braking at Mars are not affected by the constraint that the Venus passage distance must be greater than 1.1 radii. For aerodynamic braking, however, there are several mission durations for which a slightly lower mission velocity is available with missions for which the passage distance is less than 1.1 radii. These are as follows:

Stopover Time	Mission Durations
0	520, 600, 640, 720
30	520, 560, 600, 640
60	520, 560, 640, 680

The Earth entry speeds associated with the minimum mission velocities for the zero- and 60-day stopovers are very close to those shown for the 30-day stopover except in the region of the discontinuities where a variation of over 1 km/sec may be found.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

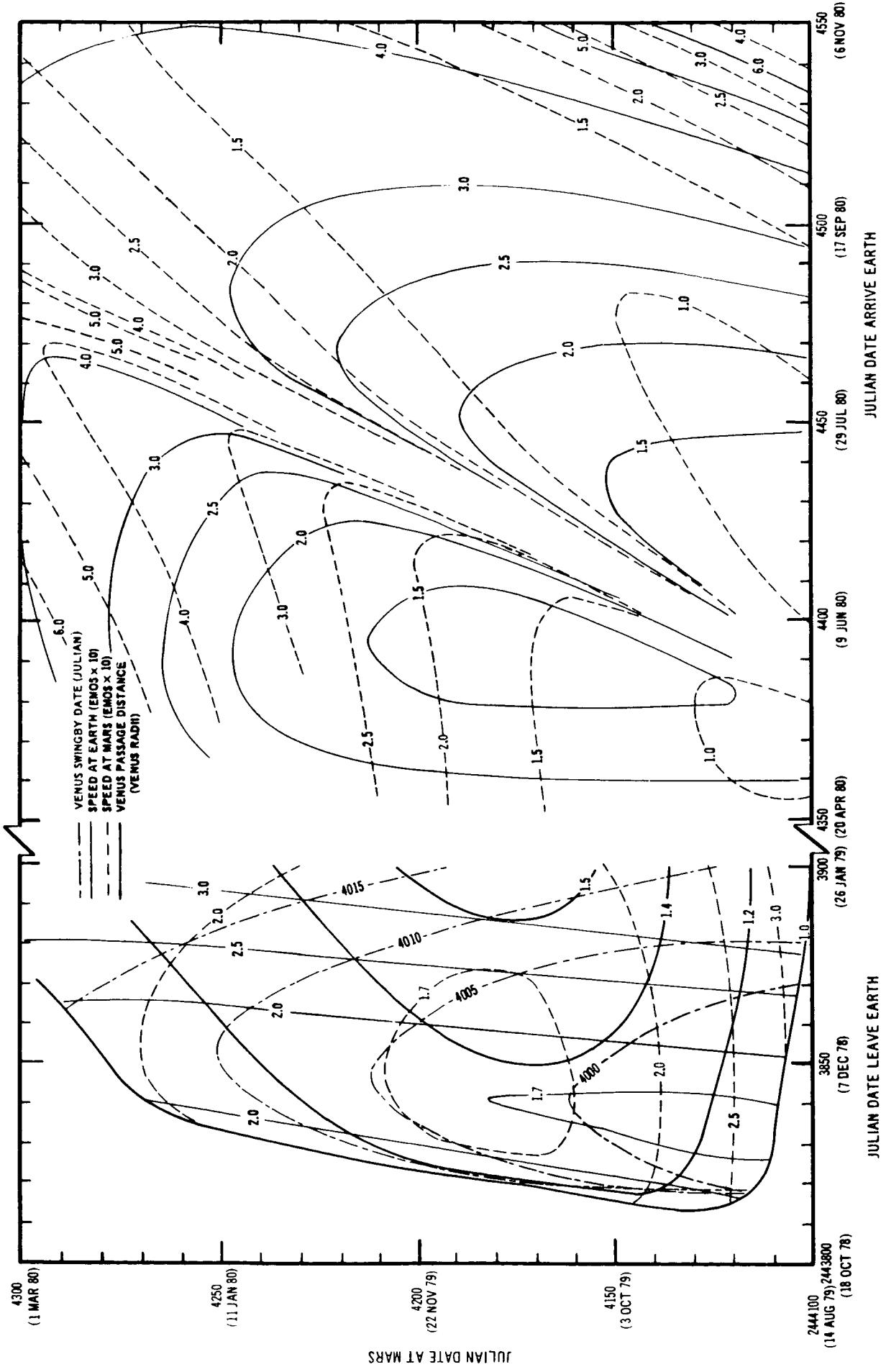


FIGURE 3-4A. 1980 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

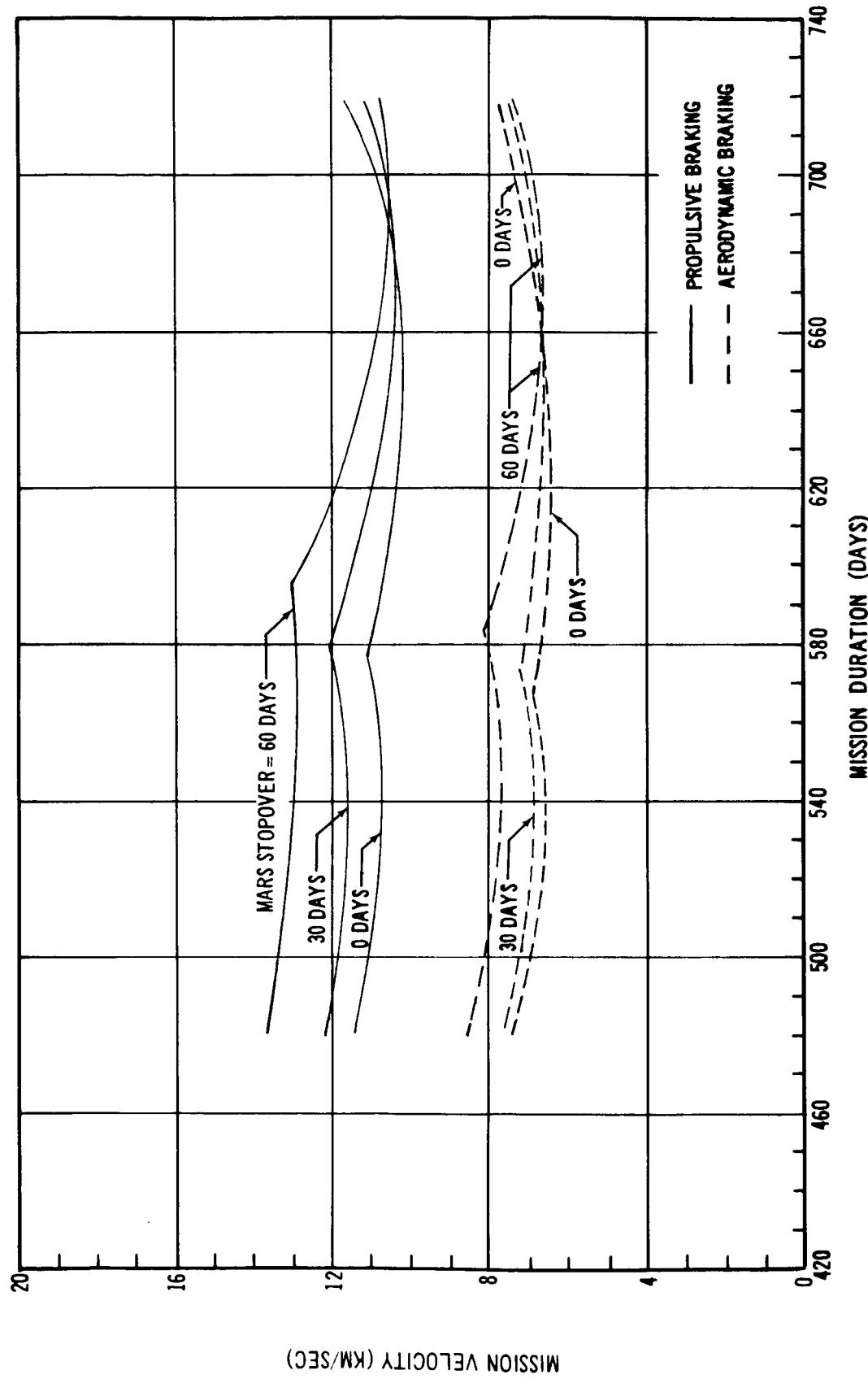


FIGURE 3-4B. 1980 OUTBOUND SWINGBY- MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

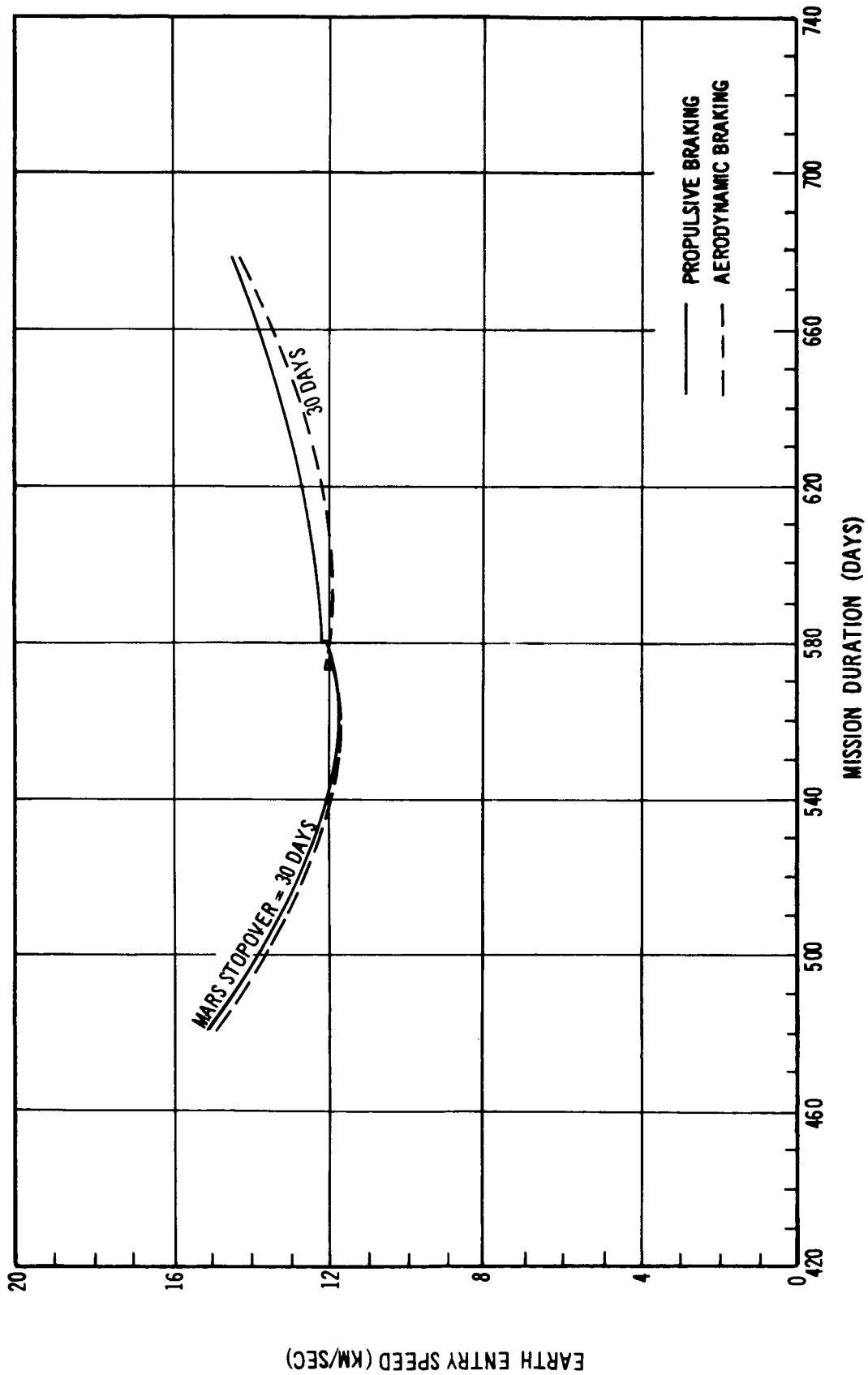


FIGURE 3-4C 1980 OUTBOUND SWINGBY - EARTH ENTRY SPEEDS

1982 INBOUND SWINGBY

This Category 3 family has Type 1 and Type 2 trajectories on the Mars-to-Venus and Venus-to-Earth legs, respectively. This is the only family available in this opportunity within the date ranges investigated. The curves on the right-hand side of the contour chart fold over one another exhibiting the three-dimensional effect described earlier.

The missions yielding minimum velocity generally fall well within the region shown on the contour chart. Therefore, the constraint on passage distance has no effect on the selections of the minimum velocity missions. The Earth entry speeds for the zero- and 60-day stopover missions are very near those shown at the larger mission durations. For the shorter mission durations, however, there exists a variation in entry speed of 1 to 2 km/sec for the three stopover times.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

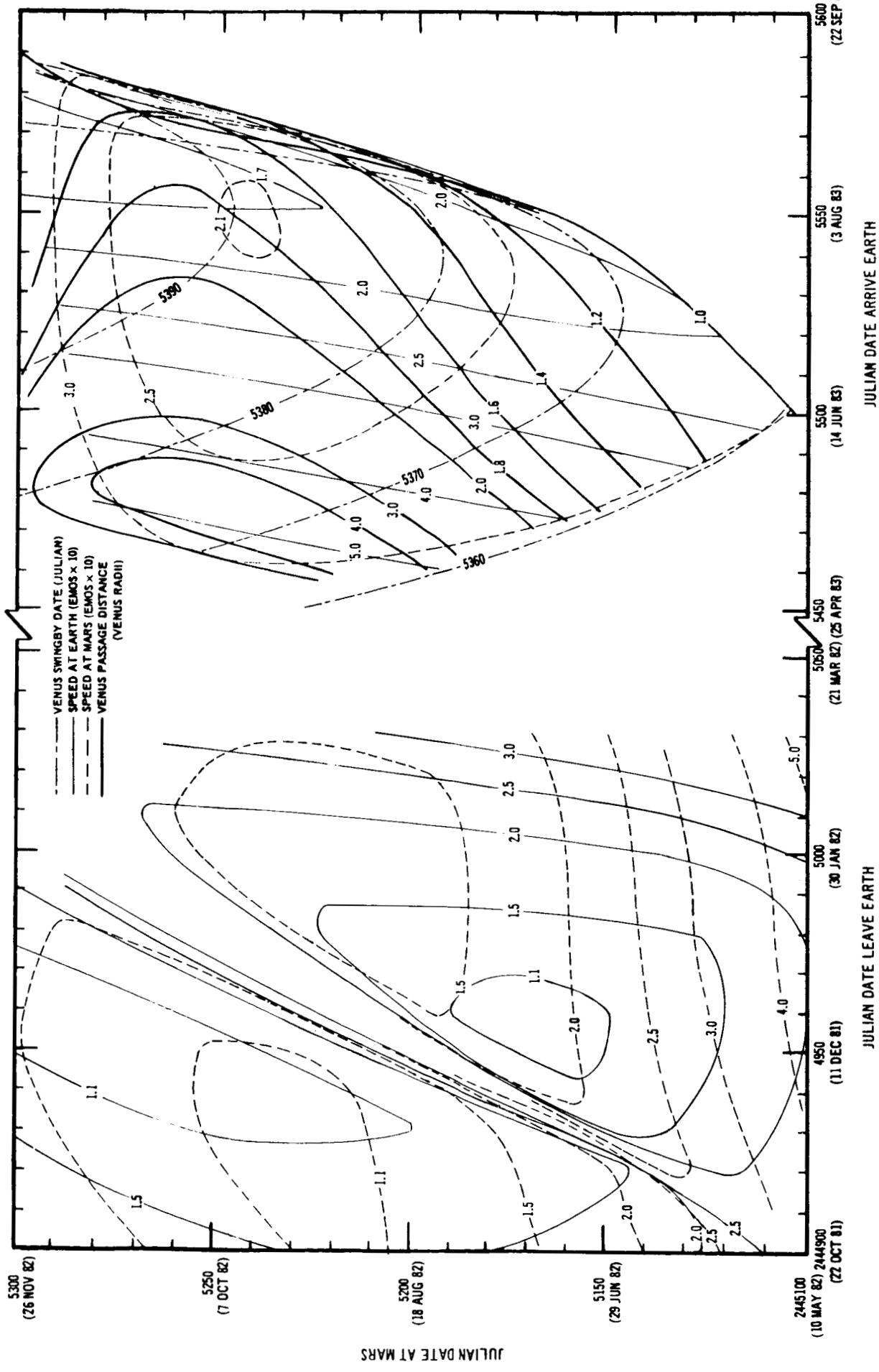


FIGURE 3-5A. 1982 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

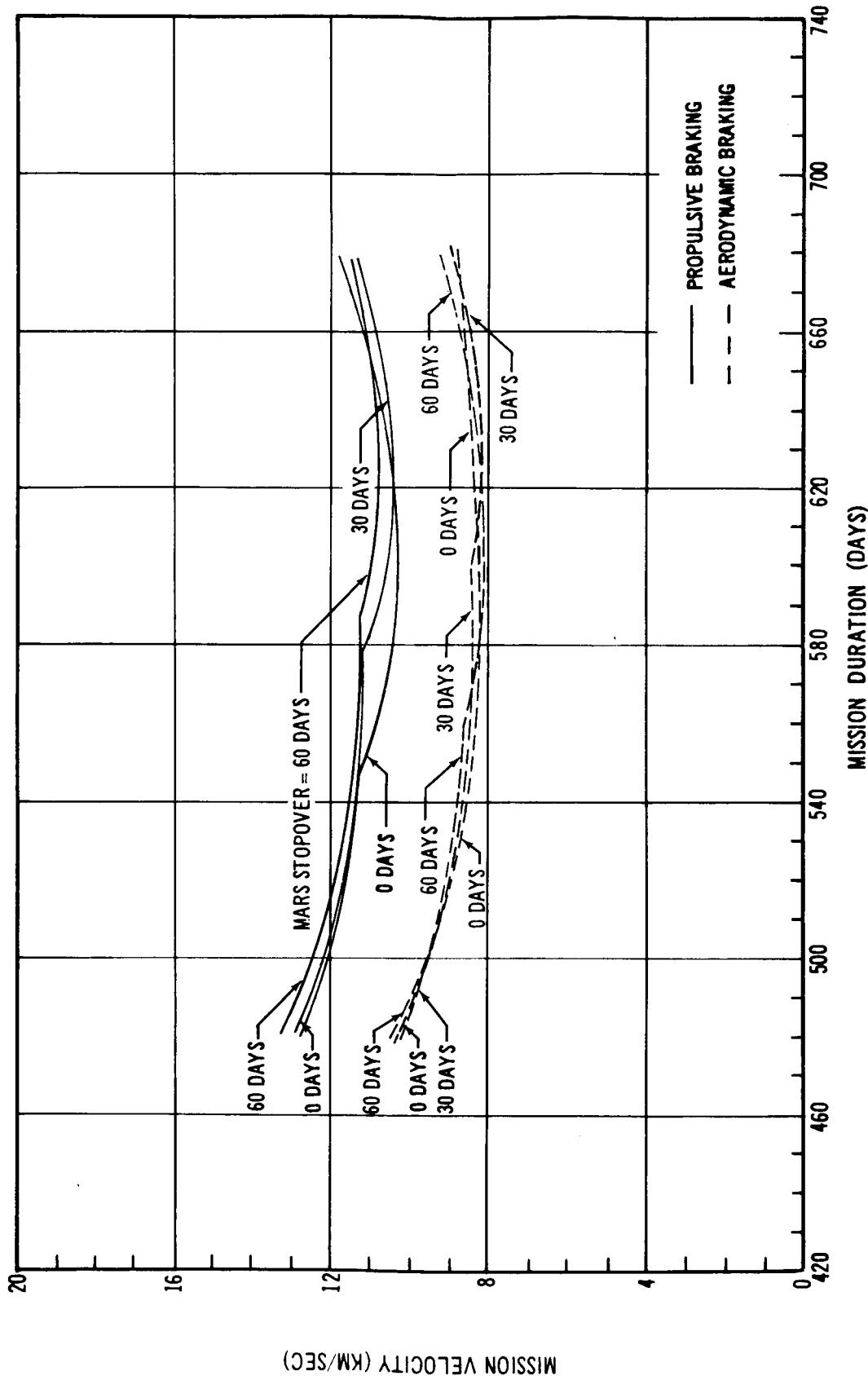


FIGURE 3 – 5B. 1982 INBOUND SWINGBY – MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

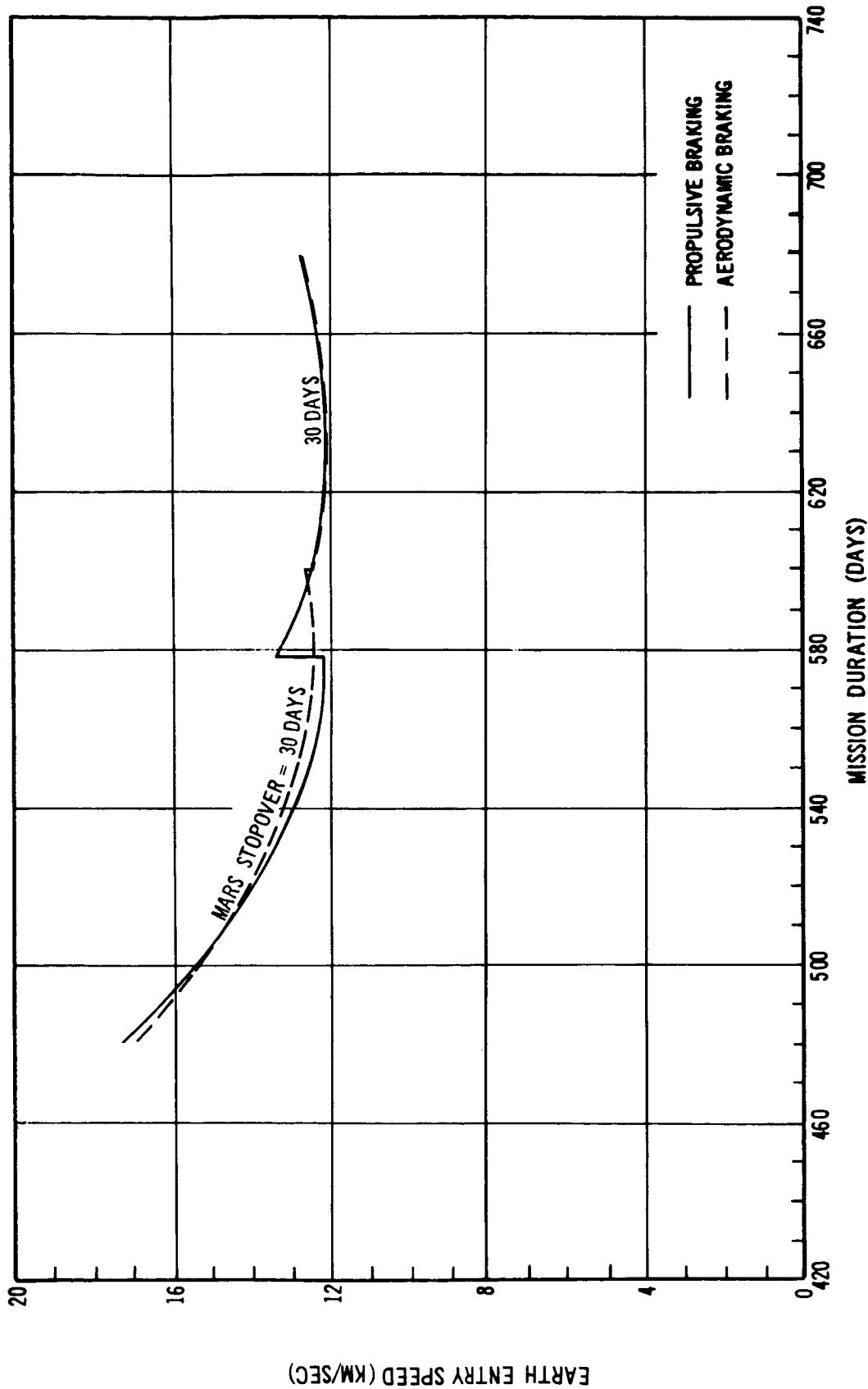


FIGURE 3-5C. 1982 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1984 OUTBOUND SWINGBY

The Category 5 family shown in the accompanying contour chart consists of Type 1 and Type 2 trajectories on the Earth-to-Venus and Venus-to-Mars legs, respectively.

It should be noted that there are two different families of swingby trajectories having a Type 1/2 combination (although having separate ranges of Venus swingby date) contained in the tabular data. There are also families having Type 1/1, 2/1, and 2/2 combinations contained in the tabular data. Generally, these families lie above and to the left of the family shown with the exception of the Type 1/1 family which lies to the right.

With the exception of the 480, 520, and 560 day mission durations for the propulsive braking, zero-day stopover curve, all of the minimum velocity missions are on or very near the Venus passage distance constraint of 1.1 Venus radii. Furthermore, for the 680 day mission duration, all minimum velocity missions employ a direct return leg with an Earth return date at the boundary of the range investigated.

Except for the longest mission durations, the Earth entry speeds associated with the minimum velocities for the zero- and 60-day stopover times are within about 1 km/sec of those for 30-day stopover times. At the 640 day mission duration, the variation is 2 km/sec.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

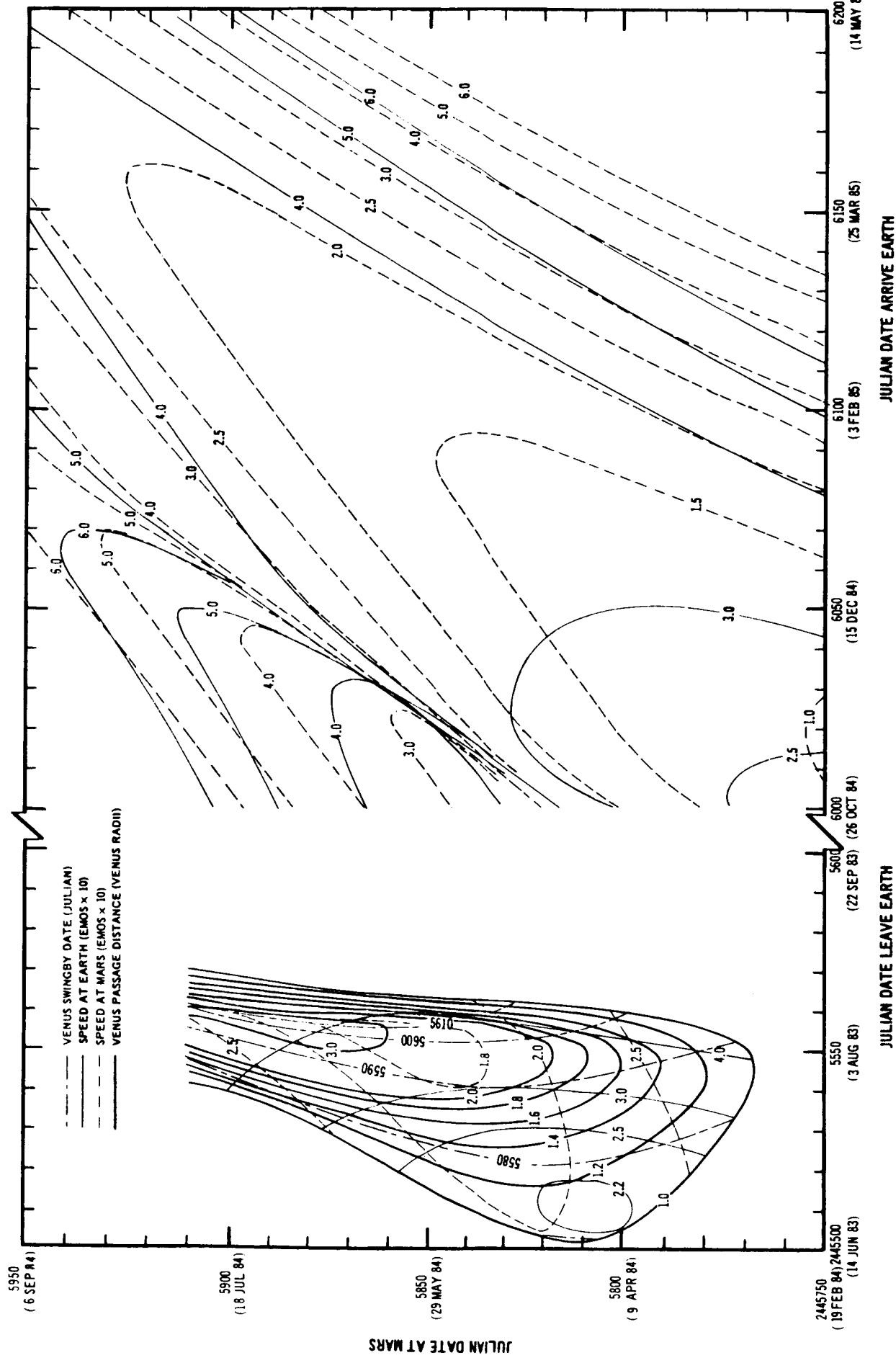


FIGURE 3-6 A. 1984 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

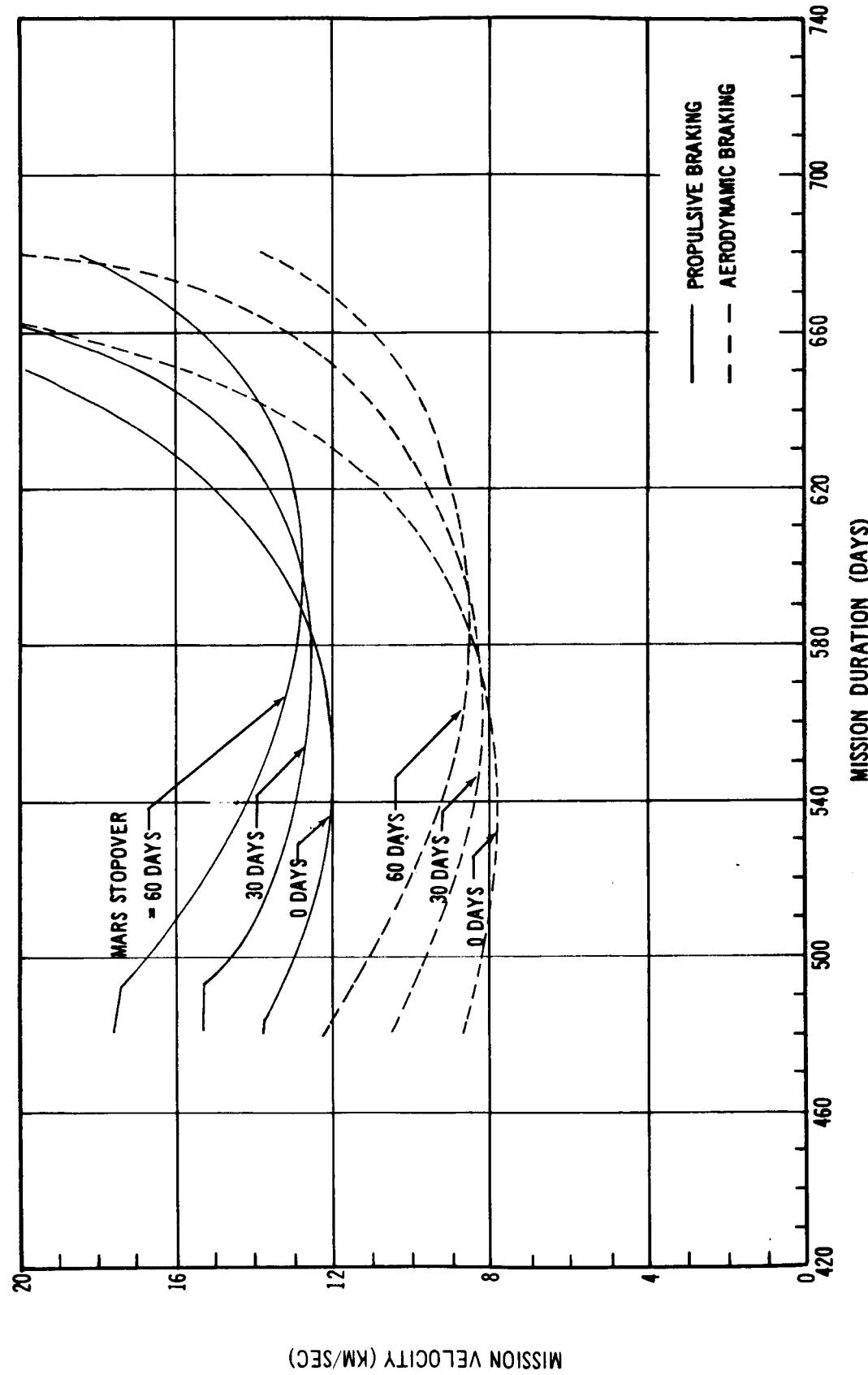


FIGURE 3 - 6B. 1984 OUTBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

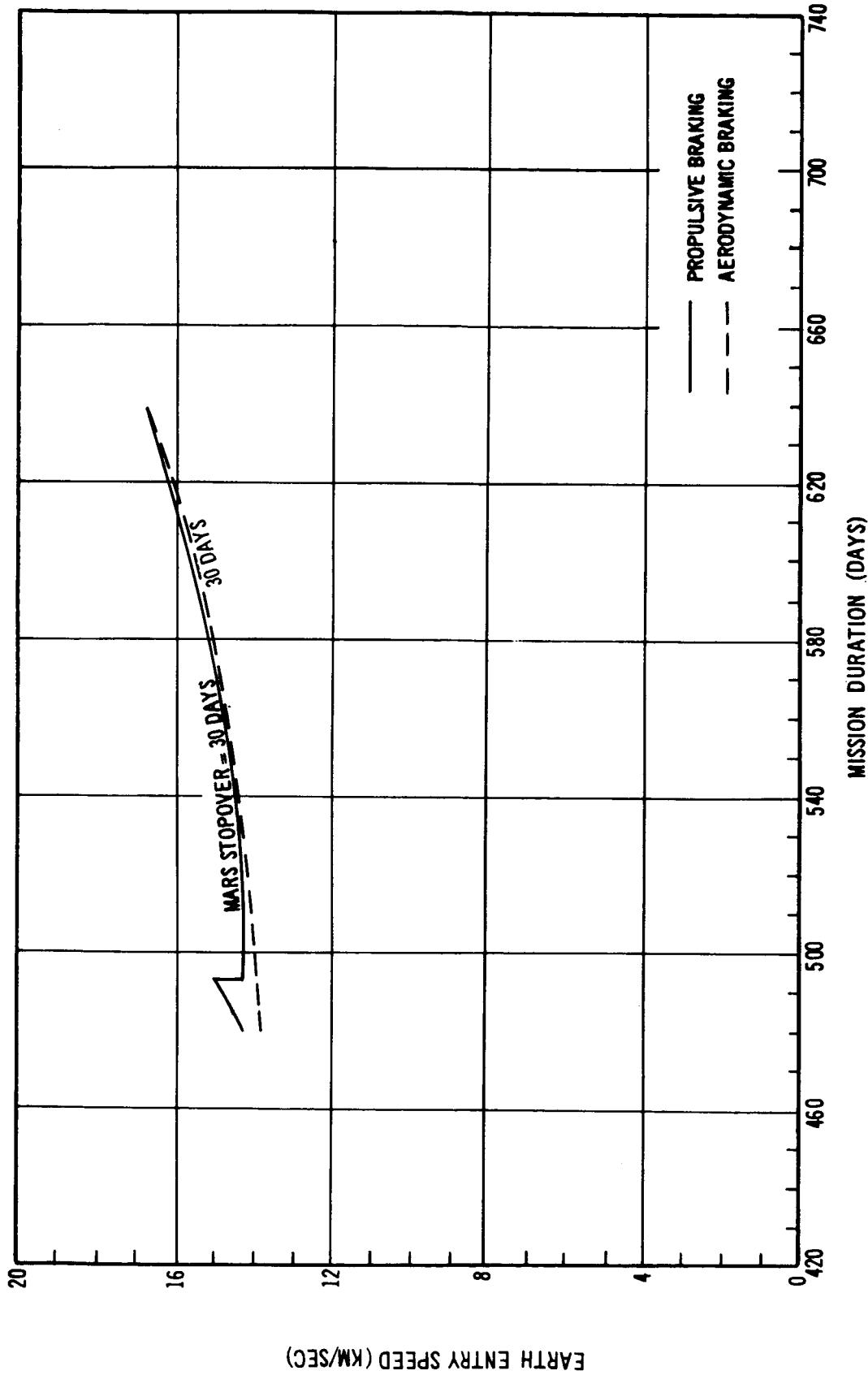


FIGURE 3-6C. 1984 OUTBOUND SWINGBY - EARTH ENTRY SPEEDS

1984 INBOUND SWINGBY

The Category 5 family shown in the contour chart consists of Type 2 trajectories for the Mars-to-Venus leg and Type 1 trajectories for the Venus-to-Earth leg. There also is another family with the same Type 2/1 combination in the tabular data. This other family is characterized by a narrow range of swingby dates around 244 6100. There is also available in this opportunity a variety of other families of solutions with Type 1/1, 1/2, and 2/2 combinations. Several of these could be considered competitive with the family shown.

For the most part, the minimum mission velocities are not affected by the Venus passage distance constraint. The exceptions are:

	Stopover Times	Mission Durations
Propulsive Braking	{ 0	520, 640
	30	640
	60	640
Aero Braking	{ 0	480, 640
	30	520, 640
	60	440

None of the minimum velocity missions employ trajectories at the boundaries of the date ranges investigated.

The Earth entry speeds associated with the minimum velocity missions are somewhat sensitive to mission duration in the vicinity of the discontinuity. Because of the variation in the location of the discontinuity in entry speed for the various stopover times, the differences in entry speed for zero- and 60-day stopover missions will be significant for mission durations less than about 540 days.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

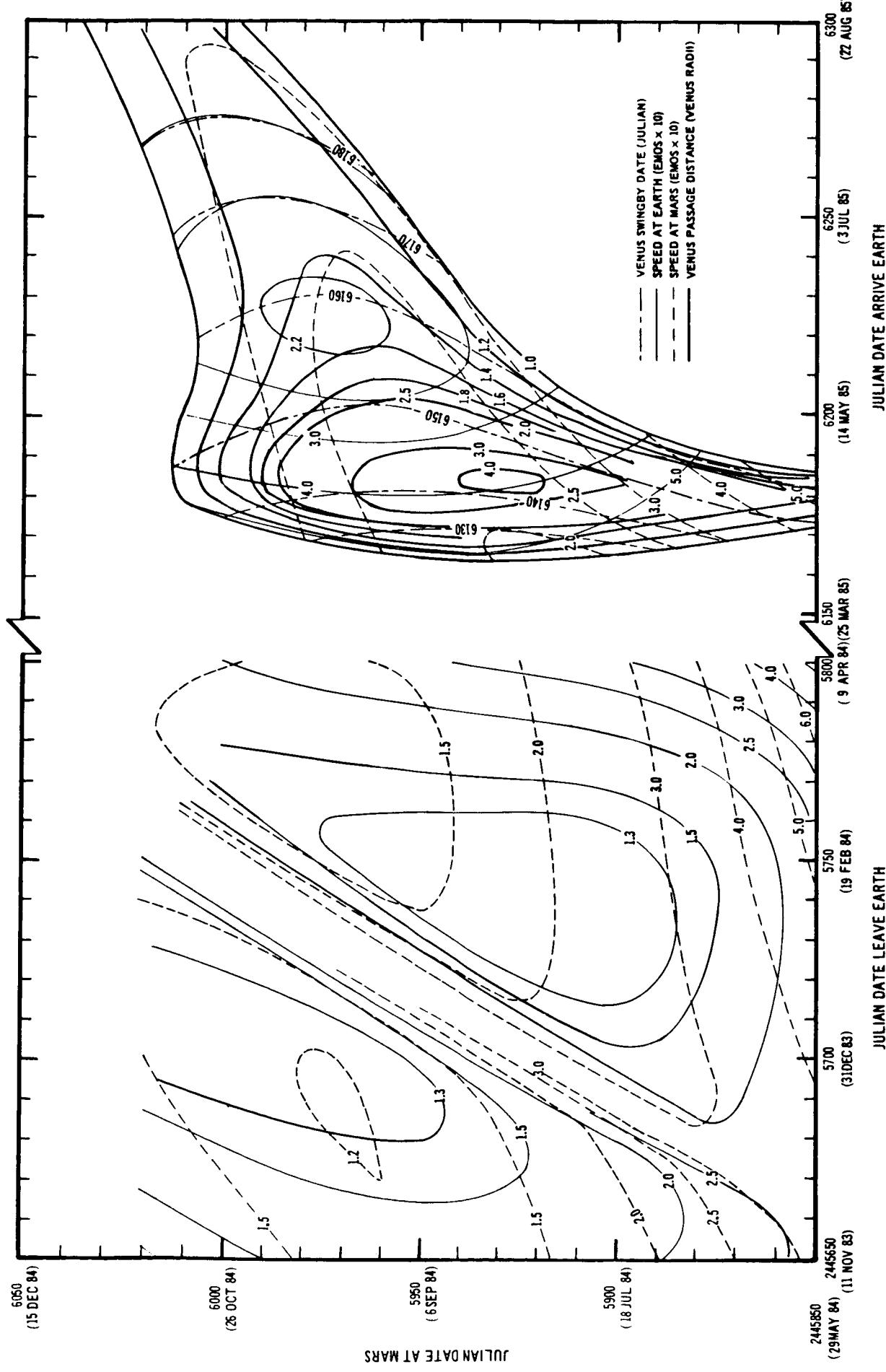


FIGURE 3-7A. 1984 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

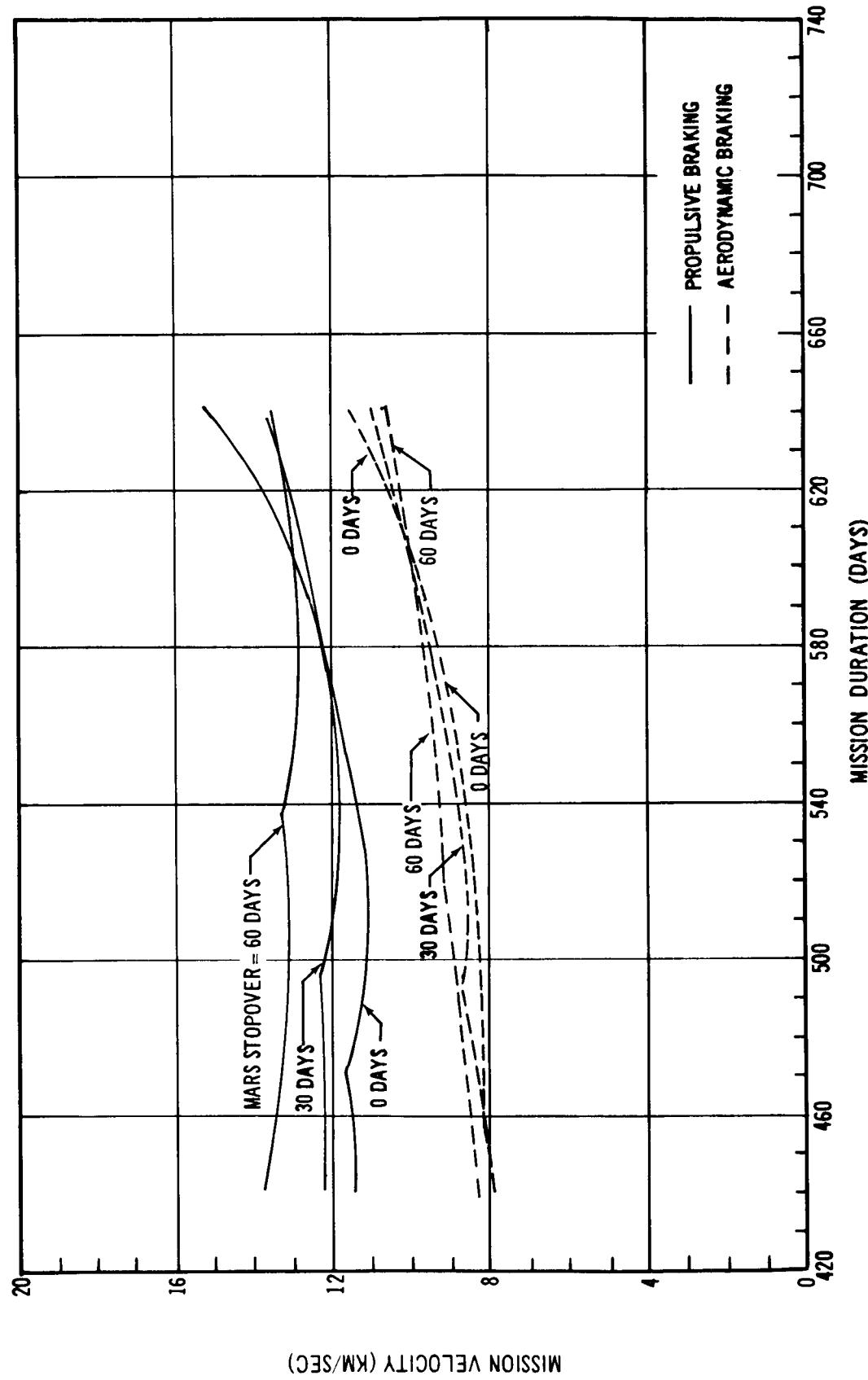


FIGURE 3 - 7B. 1984 INBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

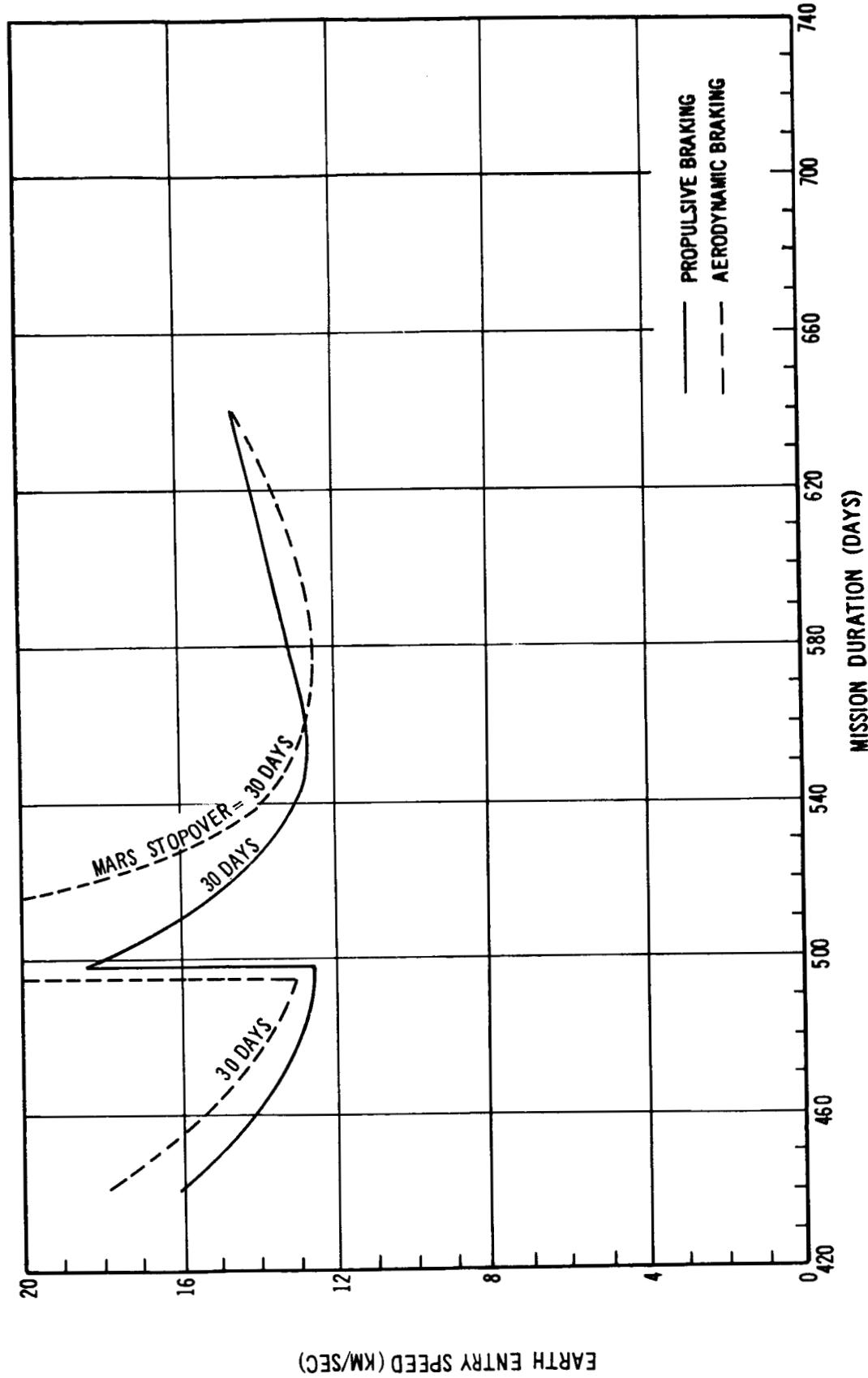


FIGURE 3 - 7C. 1984 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1986 OUTBOUND SWINGBY

The swingby trajectories in this opportunity are Category 3 missions and have Type 2 and Type 1 trajectories on the Earth-to-Venus and Venus-to-Mars legs, respectively. This is one of the few Category 3 mission opportunities for which there exist more than the one favorable family within the date ranges investigated. The family not shown also has a Type 2/1 combination and has only slightly earlier Venus swingby dates. A contour chart of this other family would cover the same Earth departure and Mars arrival date ranges as those of the family shown.

The minimum velocity missions for 60-day stopover times using aerodynamic braking at Mars are, except for the 680 day mission duration, all restricted by the Venus passage distance constraint. All other minimizing missions appear to be stationary minima. Although barely noticeable, the mission velocity curves do possess cusps. The cusps are less predominant in this opportunity because the transition between Type 1 and Type 2 trajectories occurs near the Mars-Earth nodal crossing.

The location of the cusps are somewhat more predominant on the Earth entry speed chart. The entry speeds associated with the minimum velocities for the zero- and 60-day stopover times are within 1/2 km/sec of those shown for the 30-day stopover for the entire range of mission durations.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

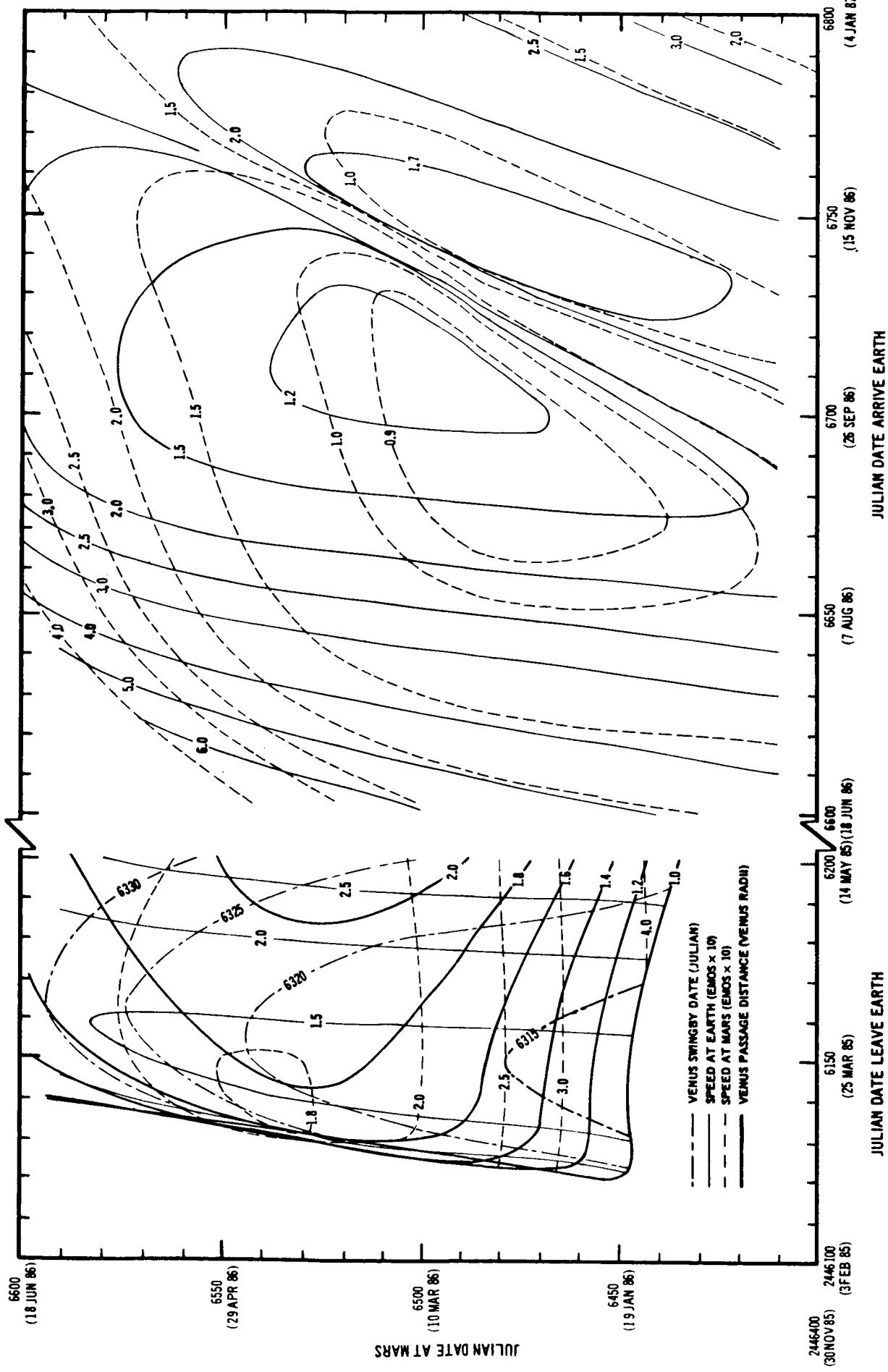


FIGURE 3-8A. 1986 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

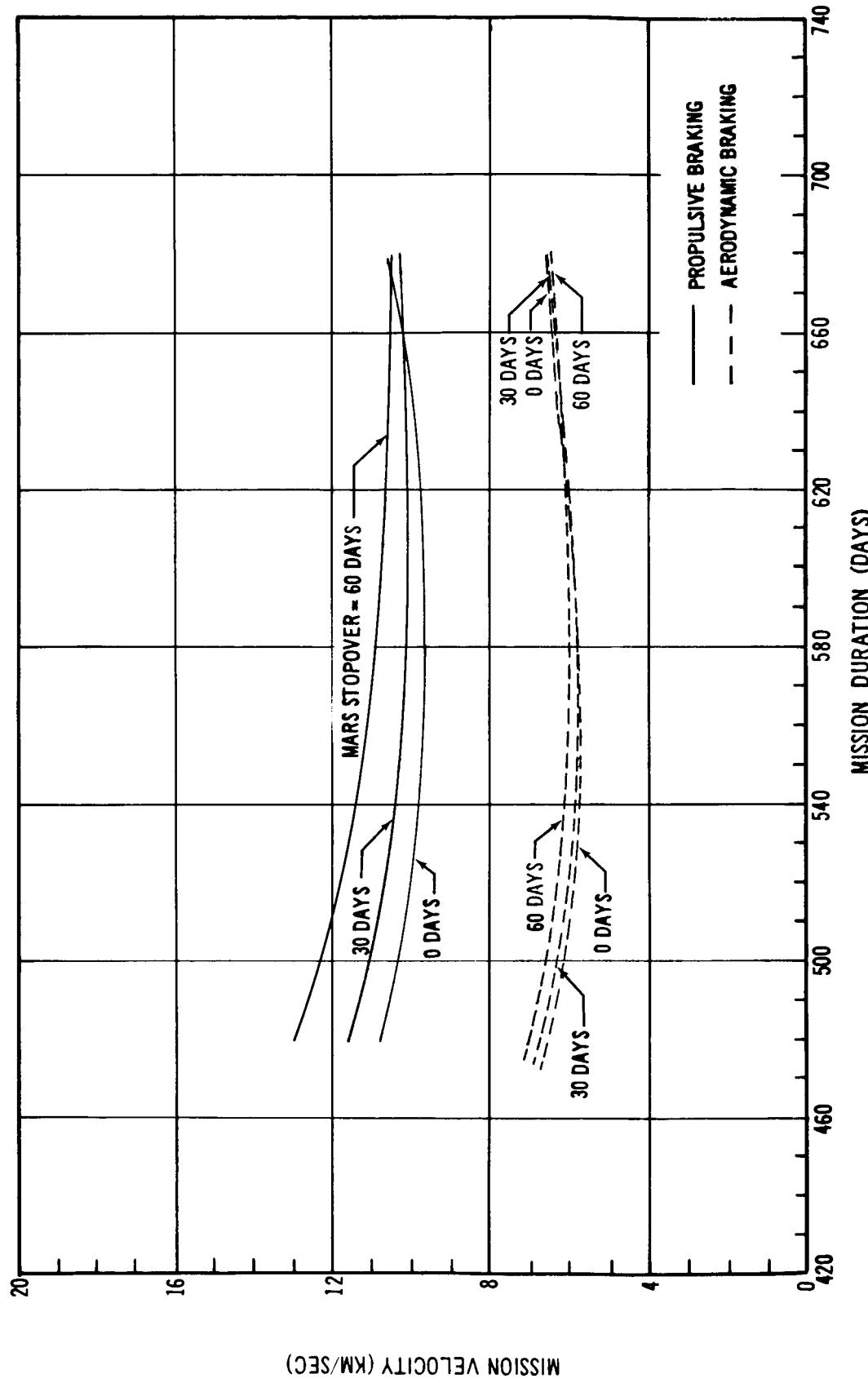


FIGURE 3 - 8B. 1986 OUTBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

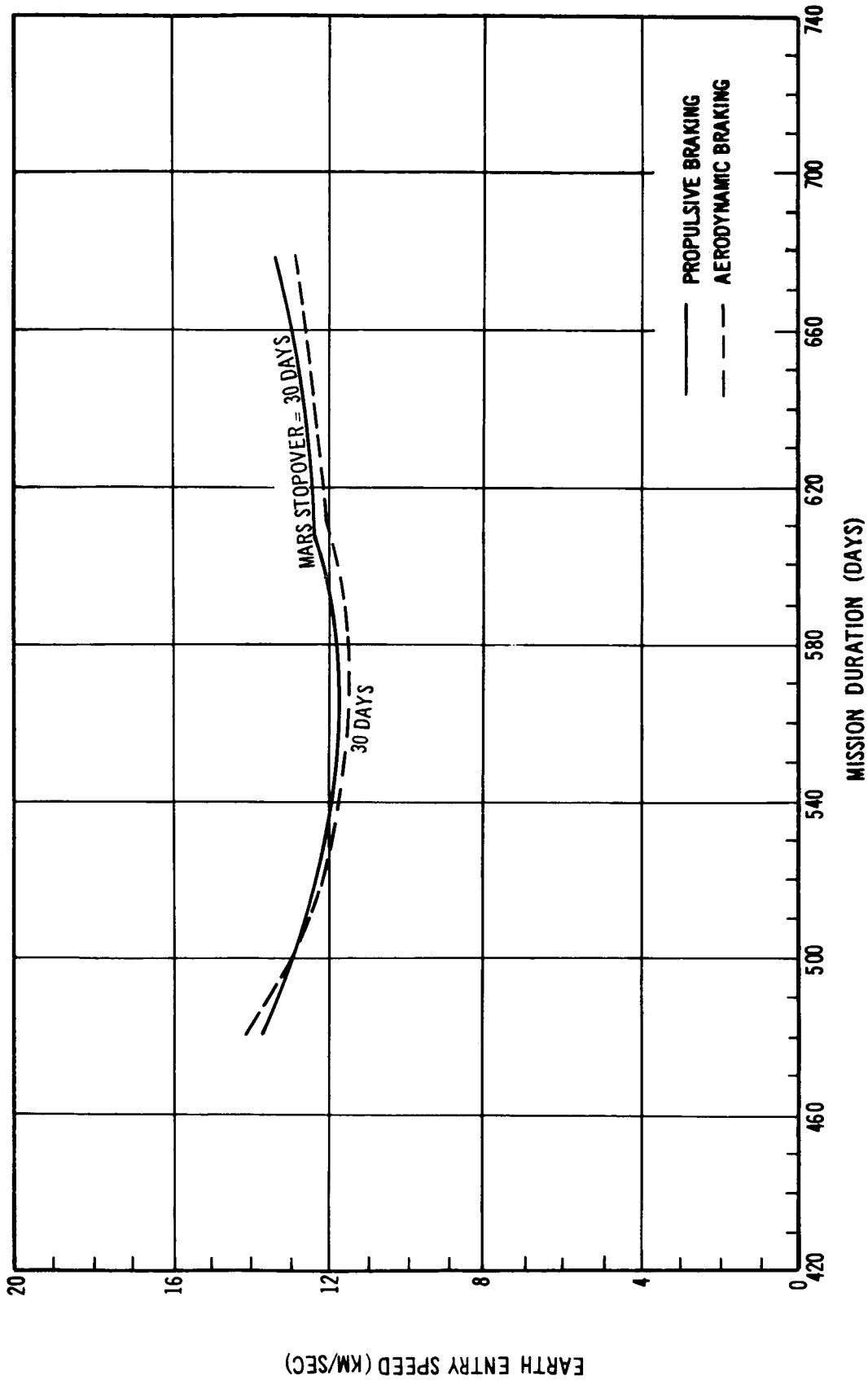


FIGURE 3-8C. 1986 OUTBOUND SWINGBY - EARTH ENTRY SPEEDS

1988 INBOUND SWINGBY

This is a Category 3 swingby opportunity employing Type 1 and Type 2 trajectories from Mars to Venus and from Venus to Earth, respectively. The existence of multiple solutions in the region on the right-hand side of the contour chart is indicated by the crossing of the constant passage distance contours. An unusual feature in this family is the cut-out in the lower right corner of the swingby contours. Physically, the cutout is due to the fact that within this family of solutions, the excess speed required at Venus departure is less than the minimum possible Venus arrival speed. A similar situation occurs in the 1999 outbound opportunity.

The minimum mission velocities are stationary minima for the mission durations less than 600 days. For the longer mission durations, the minimum missions lie near the right-hand edge of the swingby leg contours. The Earth entry speeds for the zero and 60-day stopovers are generally within 1/2 km/sec for all mission durations shown.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

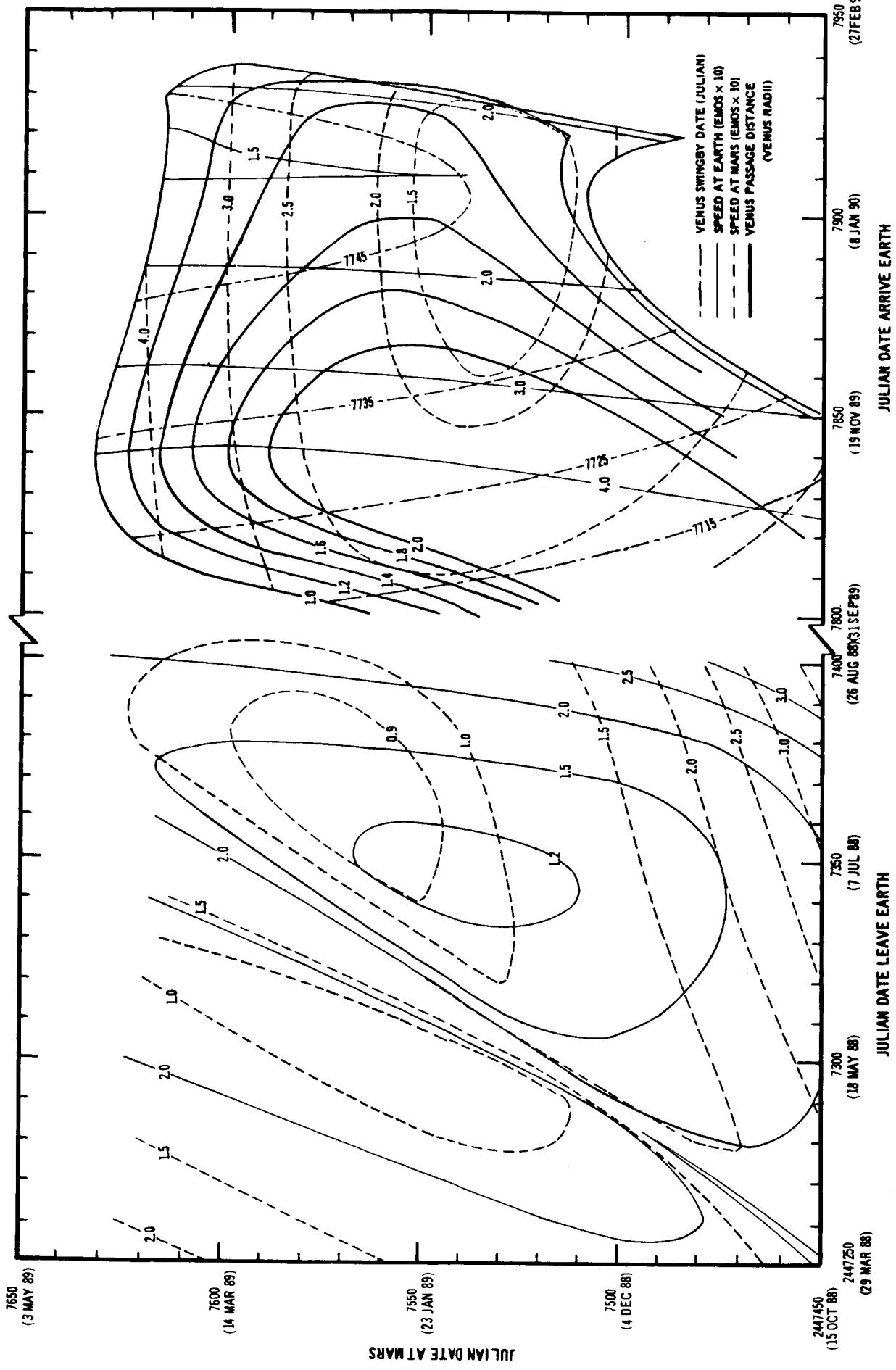


FIGURE 3-9A. 1988 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

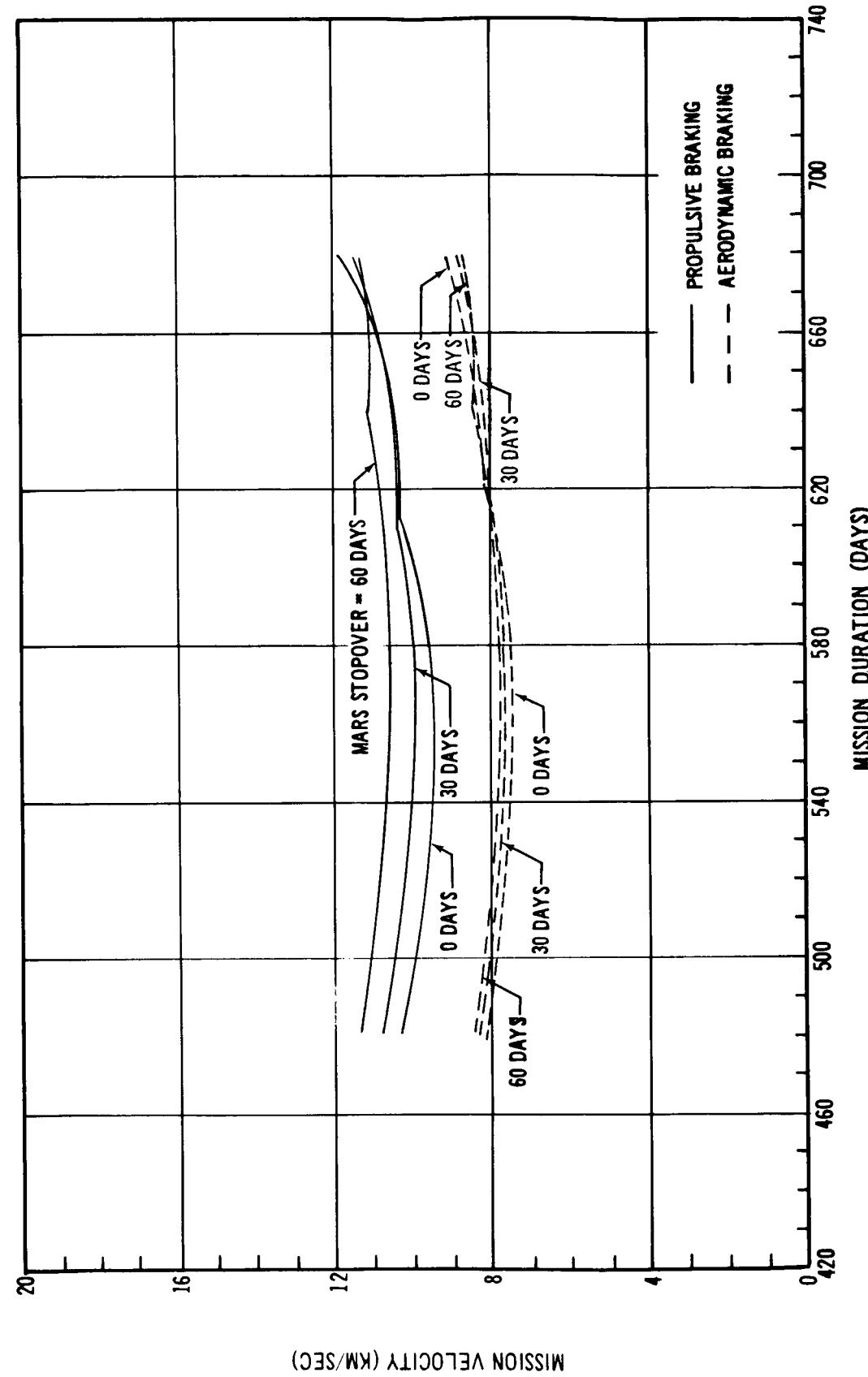


FIGURE 3 – 9B. 1988 INBOUND SWINGBY – MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

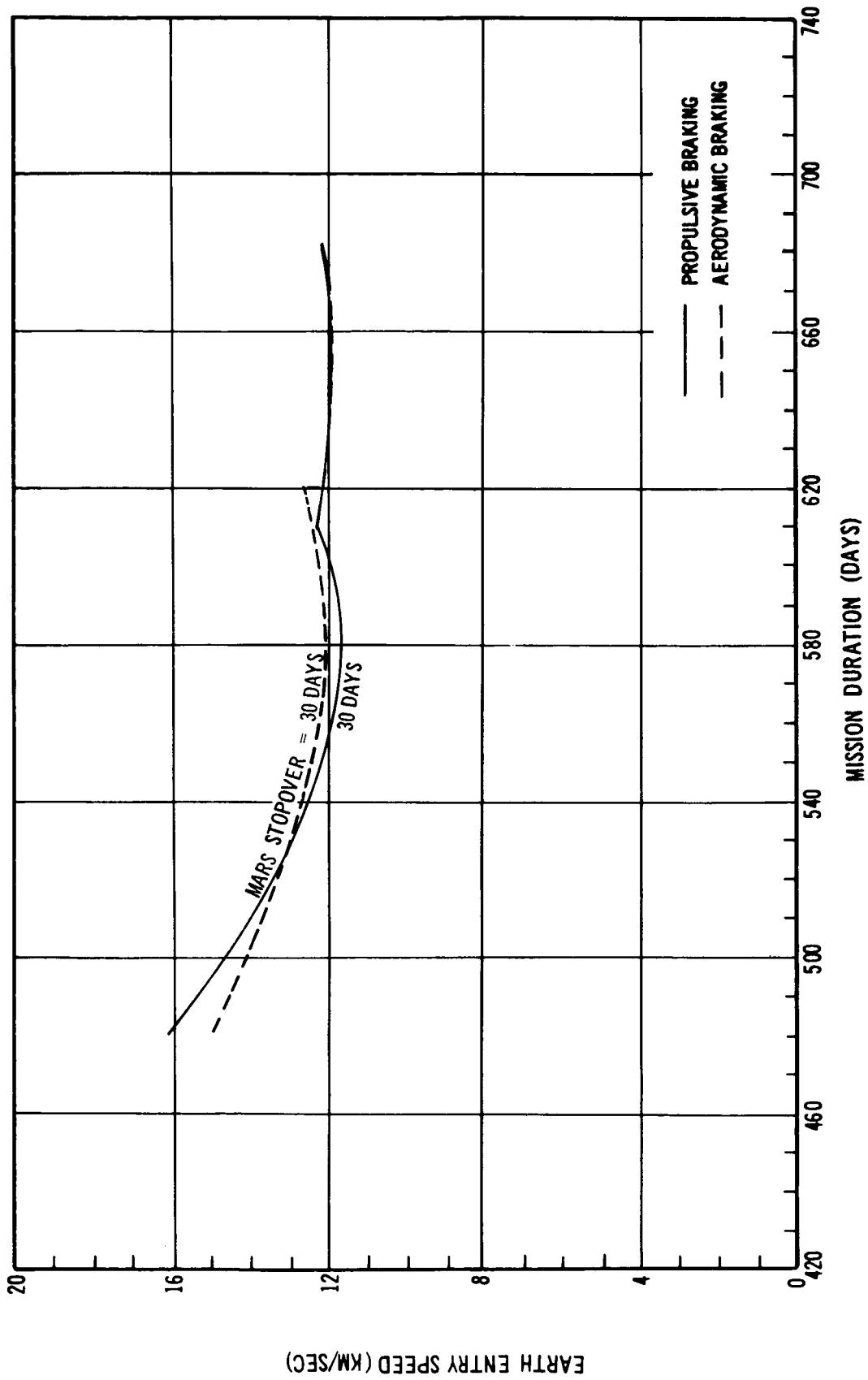


FIGURE 3-9C. 1988 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1990 OUTBOUND SWINGBY

The Category 5 family shown in the contour chart employs Type 2 and Type 1 trajectories from Earth to Venus and from Venus to Mars, respectively. Other families of solutions available in the tabular data include the Type 1/2 combination which lies generally above the swingby contours shown and the Type 1/1 combination which lies just to the right of the contours shown.

The minimum mission velocities for propulsive braking at Mars are all stationary minima. For aerodynamic braking, however, some of the minimum cases are on or very near the Venus passage distance constraint. Those that appear to be affected by the constraint are as follows:

Stopover Time	Mission Duration
0	520
30	440, 480, 520, 560
60	440, 480, 520, 560, 600

The propulsive braking minimum velocity missions for the 680 day mission duration and all three stopover times employ direct return legs with an Earth arrival date on the boundary of the date range investigated. For aerodynamic braking the same is true only for the 30 day stopover time.

The Earth entry speeds for zero- and 60-day stopovers are within 1/2 km/sec of those for 30-day stopover at all mission durations.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

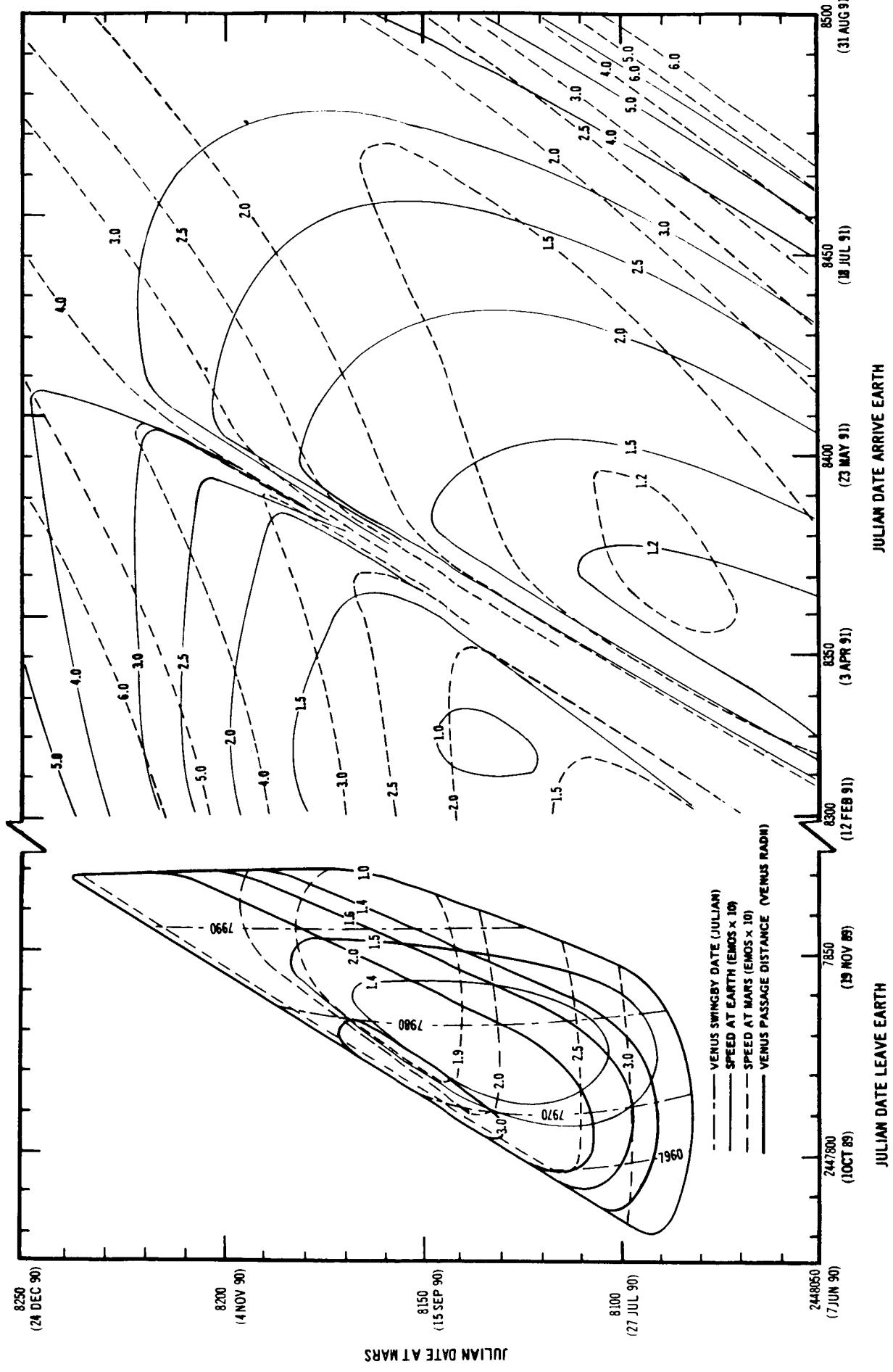


FIGURE 3-10A. 1990 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

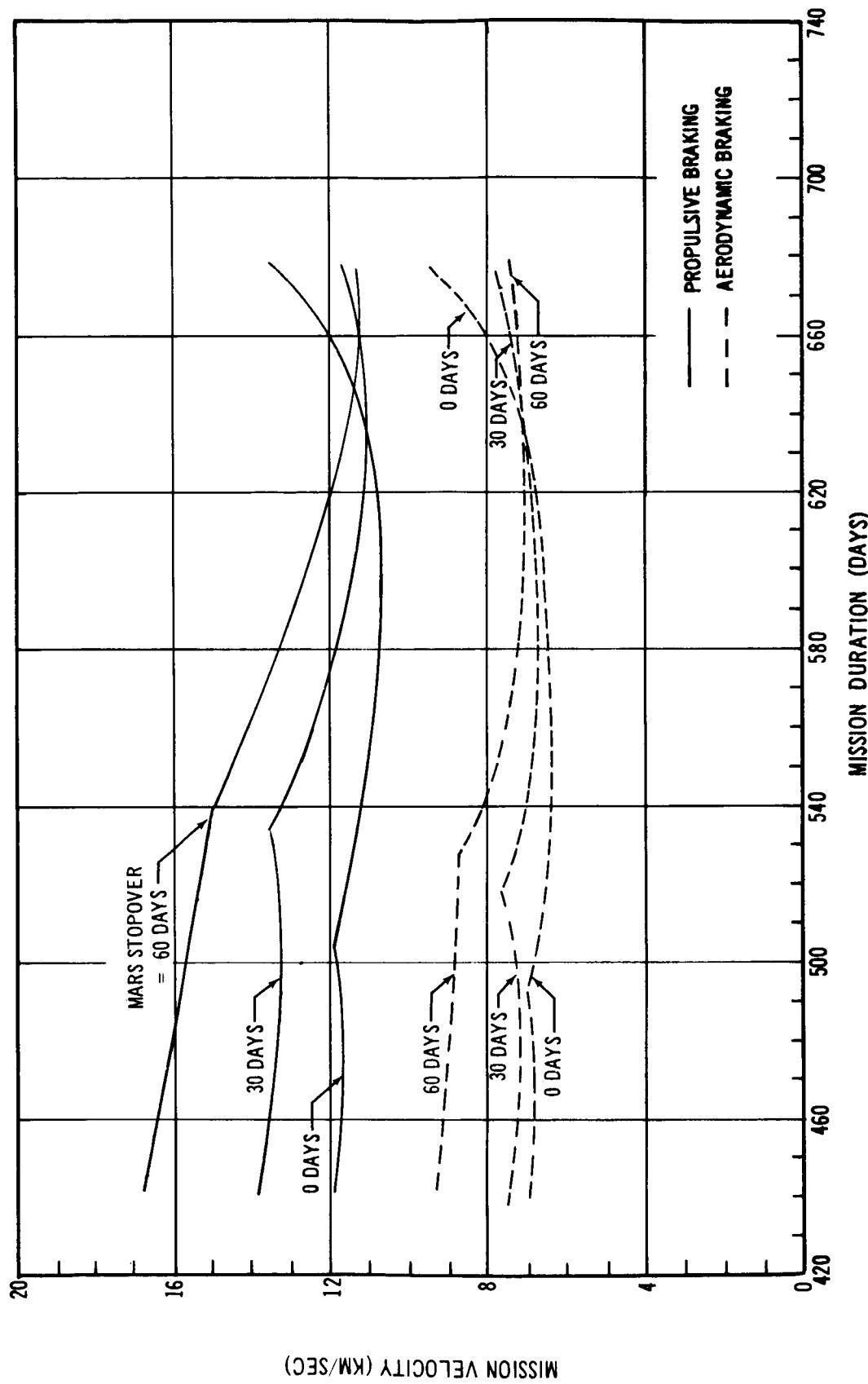


FIGURE 3 – 10B.1990 OUTBOUND SWINGBY – MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

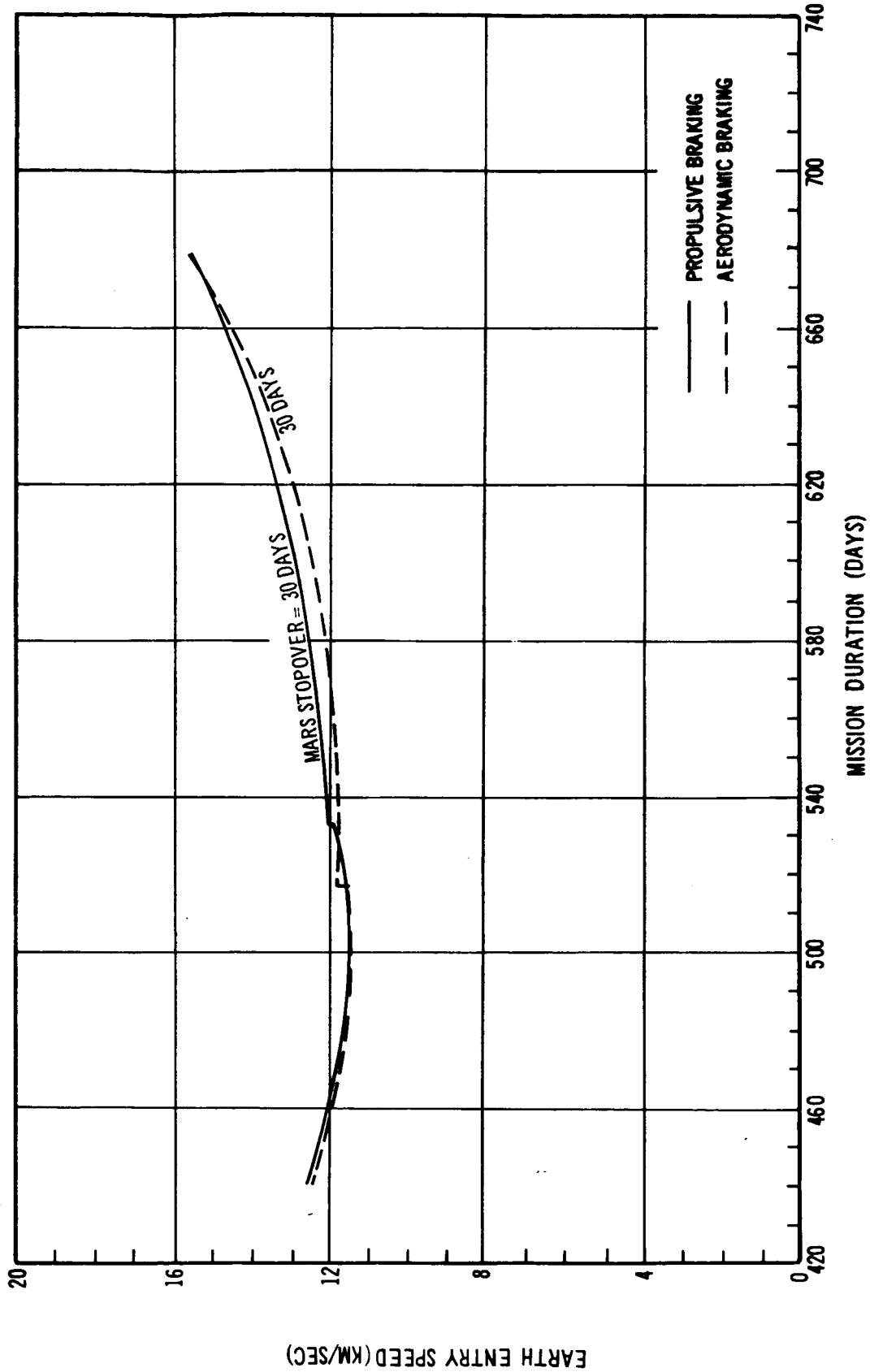


FIGURE 3-10C. 1990 OUTBOUND SWINGBY- EARTH ENTRY SPEEDS

1990 INBOUND SWINGBY

The Category 5 family shown in the contour chart employs Type 2 and Type 1 trajectories from Mars to Venus and from Venus to Earth, respectively. It should be noted that there are two different swingby families having a Type 2/1 combination as well as various families having other Type combinations listed in the tabular data. The Type 2/1 family that is not shown lies in the lower right-hand corner of the contour chart. A Type 1/1 family lies to the left of the family shown while Type 1/2 and 2/2 families are available to the right of the family shown.

Most of the minimum velocity missions lie very near the 1.1 radii Venus passage distance constraint. Those missions that appear to be stationary minima are:

	Stopover Time	Mission Duration
Propulsive Braking	0	480
	30	480, 520
	60	440, 480, 520, 560
Aero Braking	0	520
	30	520, 560
	60	520

Several of the minimum velocity missions employ outbound direct flights that lie on the boundaries of the date ranges investigated.

The Earth entry speeds for the propulsive and aero braking zero-day stopover missions and for the aero braking 60-day stopover missions generally are within about 1/2 km/sec of the corresponding curves for 30-day stopovers. The propulsive braking 60-day stopover entry speeds are higher by 1-2 km/sec than those of the corresponding 30-day stopover missions, however.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

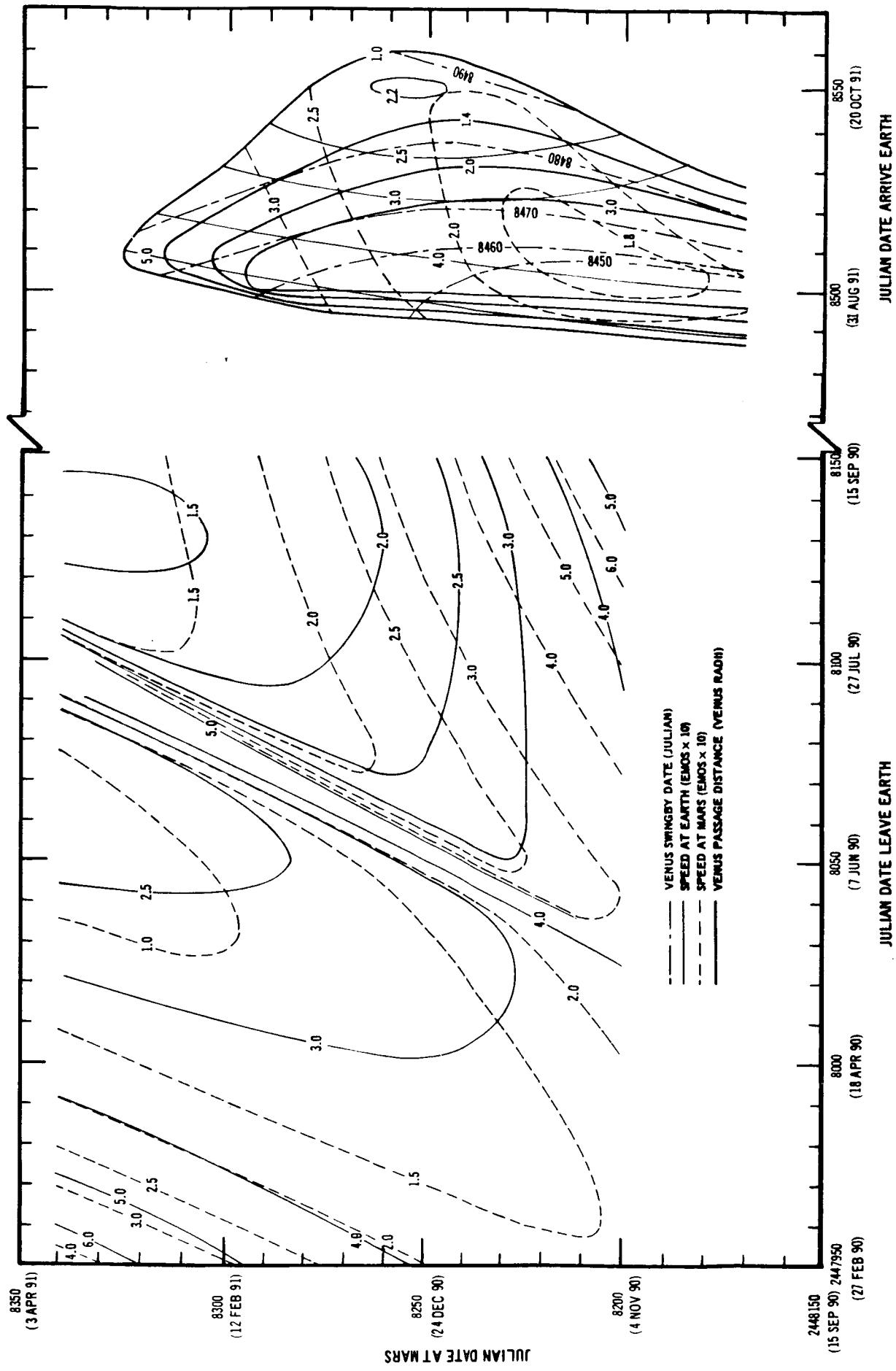


FIGURE 3-11A. 1990 INBOUND SWINGBY- CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

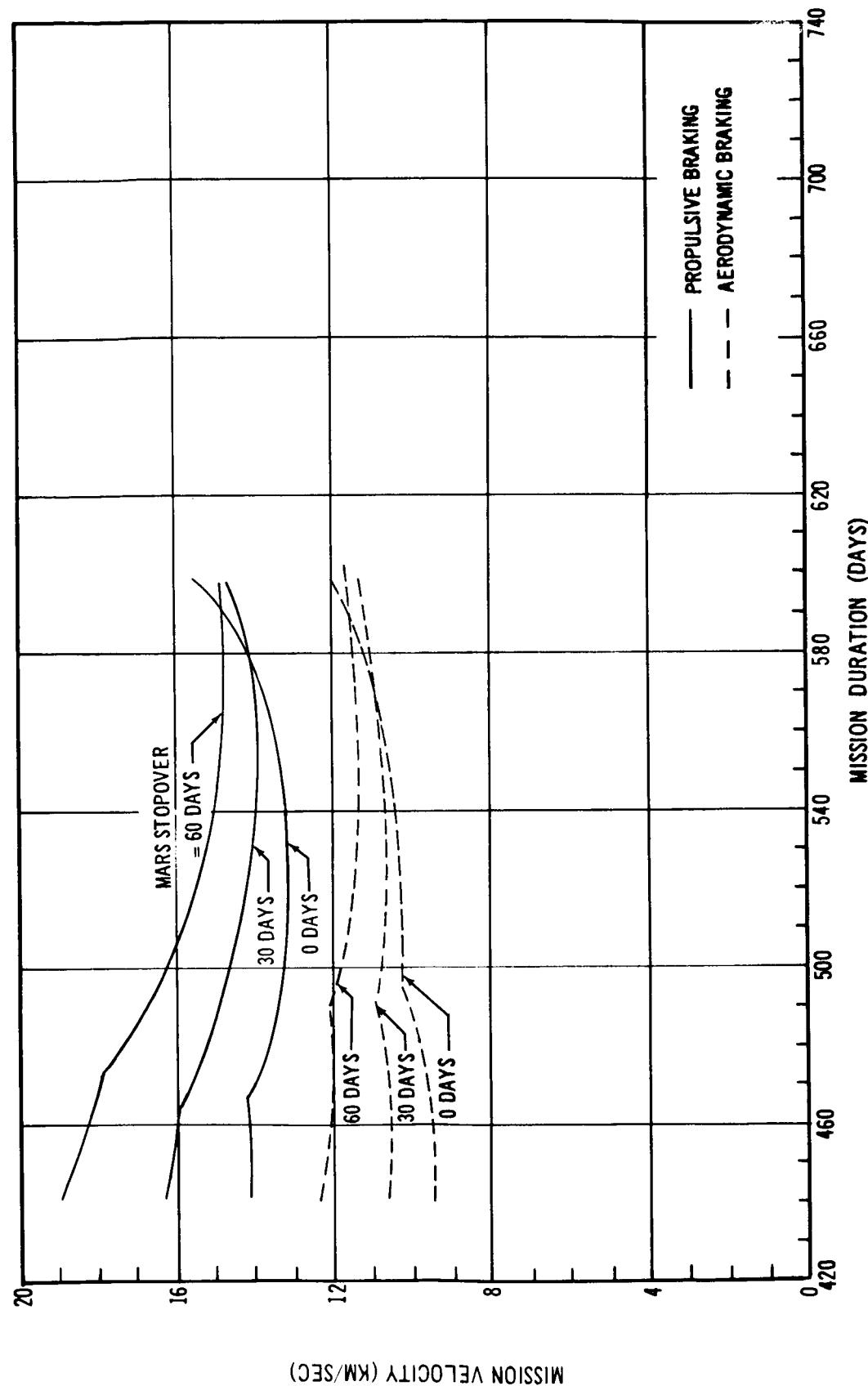


FIGURE 3 - 11B. 1990 INBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

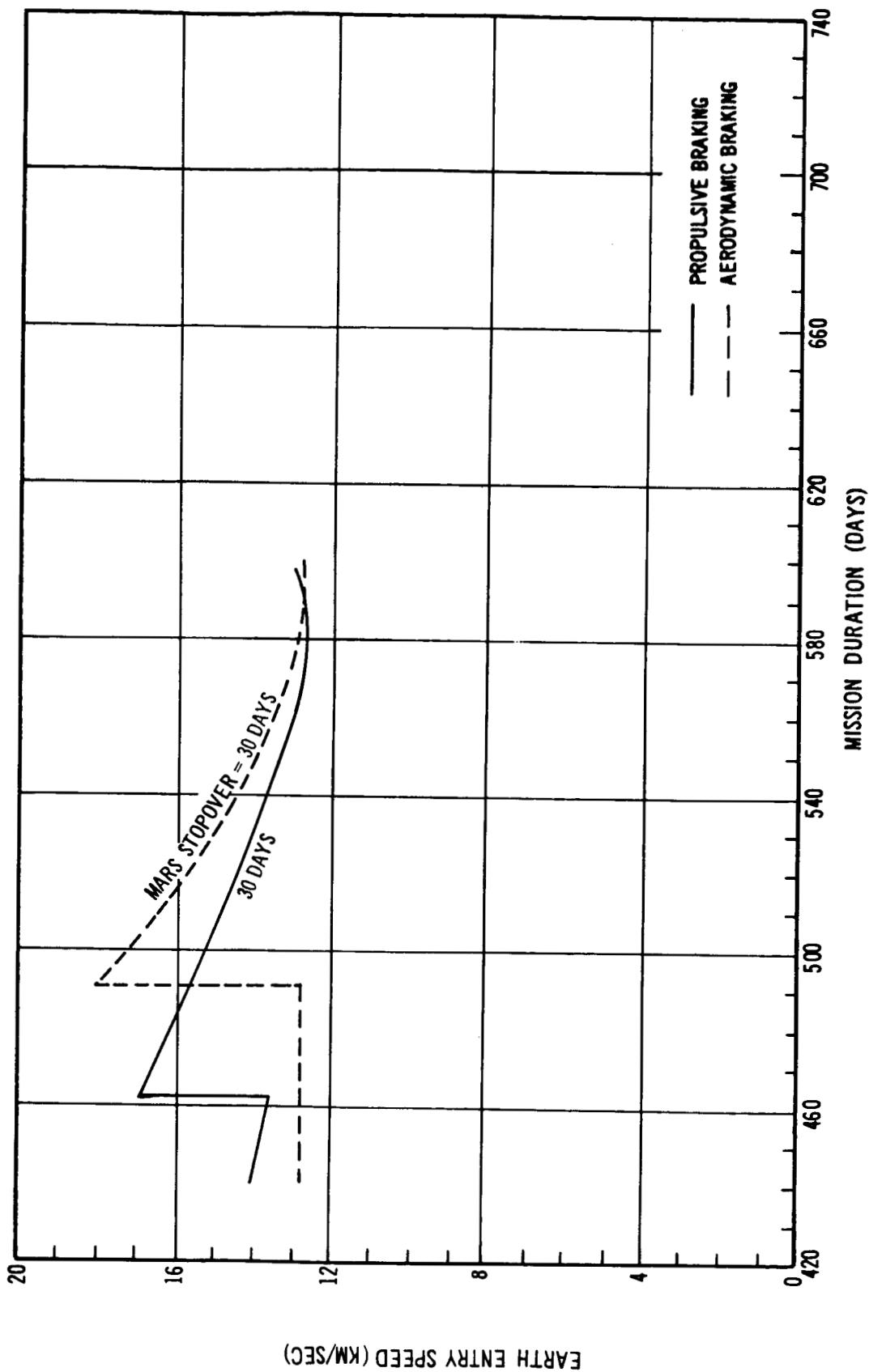


FIGURE 3-11G. 1990 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1993 OUTBOUND SWINGBY

This is a Category 3 swingby opportunity employing a Type 2 trajectory from Earth to Venus, and a Type 1 trajectory from Venus to Mars. This is the only family of solutions available for this opportunity in the date ranges investigated. The existence of multiple solutions in the region on the left side of the swingby contours is indicated by the crossing of the constant passage distance contours.

Except for the 30-day stopover, 720-day mission duration, aerodynamic braking case, no minimum velocity missions are affected by the constraint on Venus passage distance. This particular mission employs a direct return flight with an arrival date on the boundary of the range investigated.

The Earth entry speeds for zero and 60-day stopovers lie almost exactly on the curves of the 30-day stopover missions. The variation is well within 1/2 km/sec for most of the mission durations.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

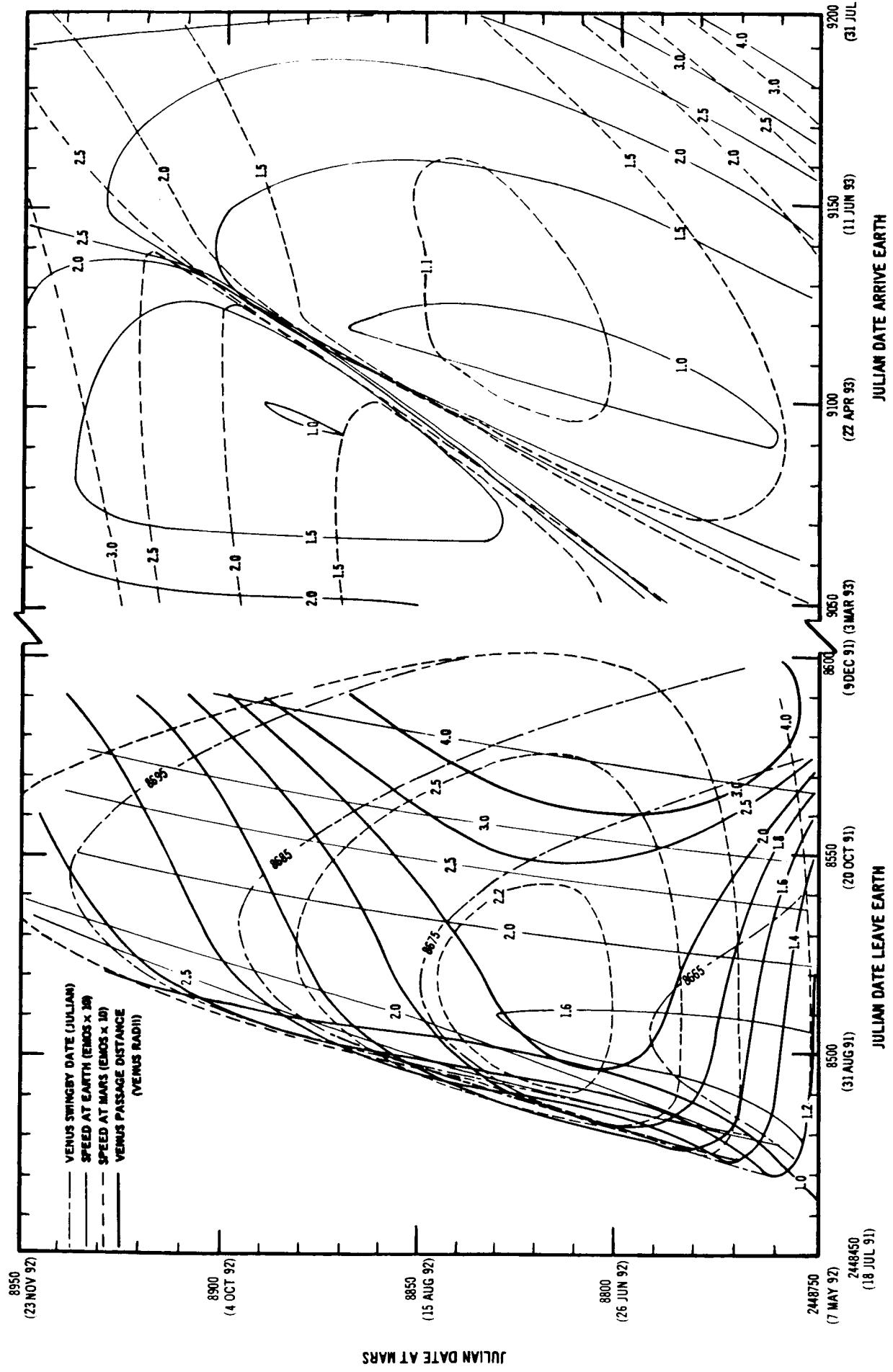


FIGURE 3-12A. 1993 OUTBOUND SWINGBY – CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

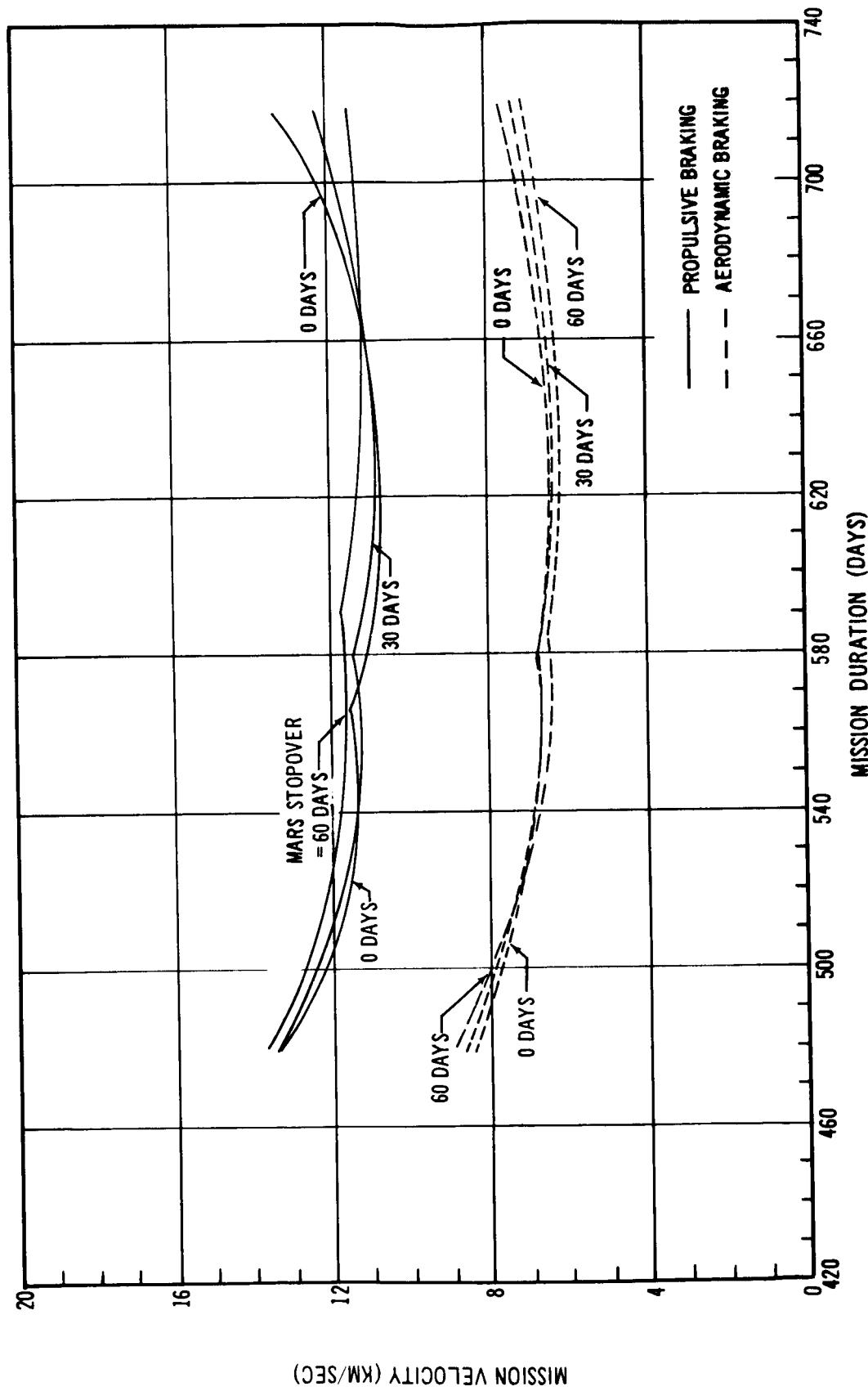


FIGURE 3-12B.1993 OUTBOUND SWINGBY- MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

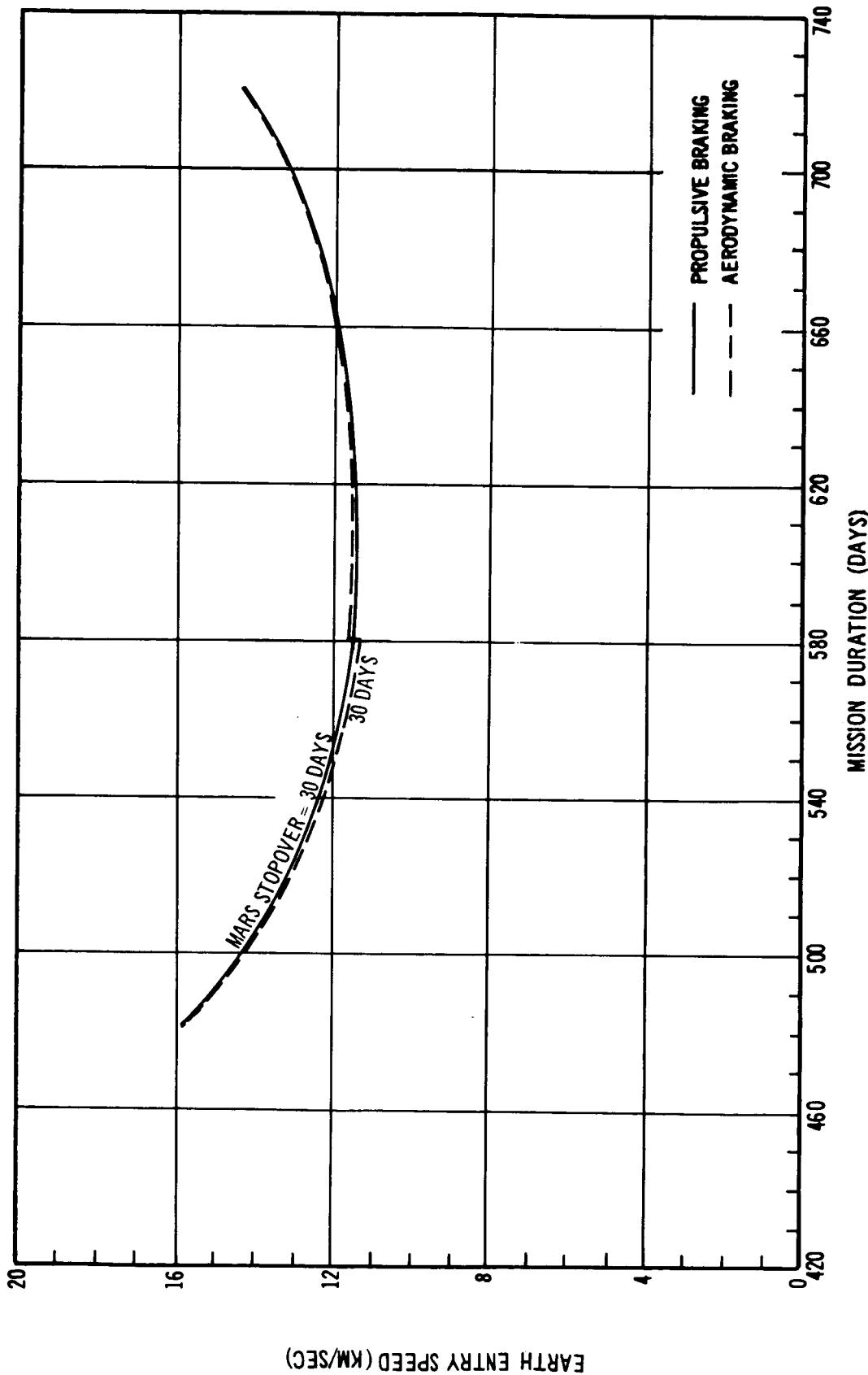


FIGURE 3-12C. 1993 OUTBOUND SWINGBY- EARTH ENTRY SPEEDS

1995 INBOUND SWINGBY

The trajectories for this Category 3 opportunity are Type 1 and Type 2 for the Mars-to-Venus and Venus-to-Earth legs, respectively. This is the only family of solutions available in this opportunity.

All of the minimum mission velocities of part B of the figure are stationary minima, and are not affected by the Venus passage distance constraint.

The Earth entry speeds for the minimum velocity missions are quite insensitive to stopover time, the maximum variation from the 30-day stopover curve being less than 1 km/sec. For most mission durations, the variation is less than 1/2 km/sec.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

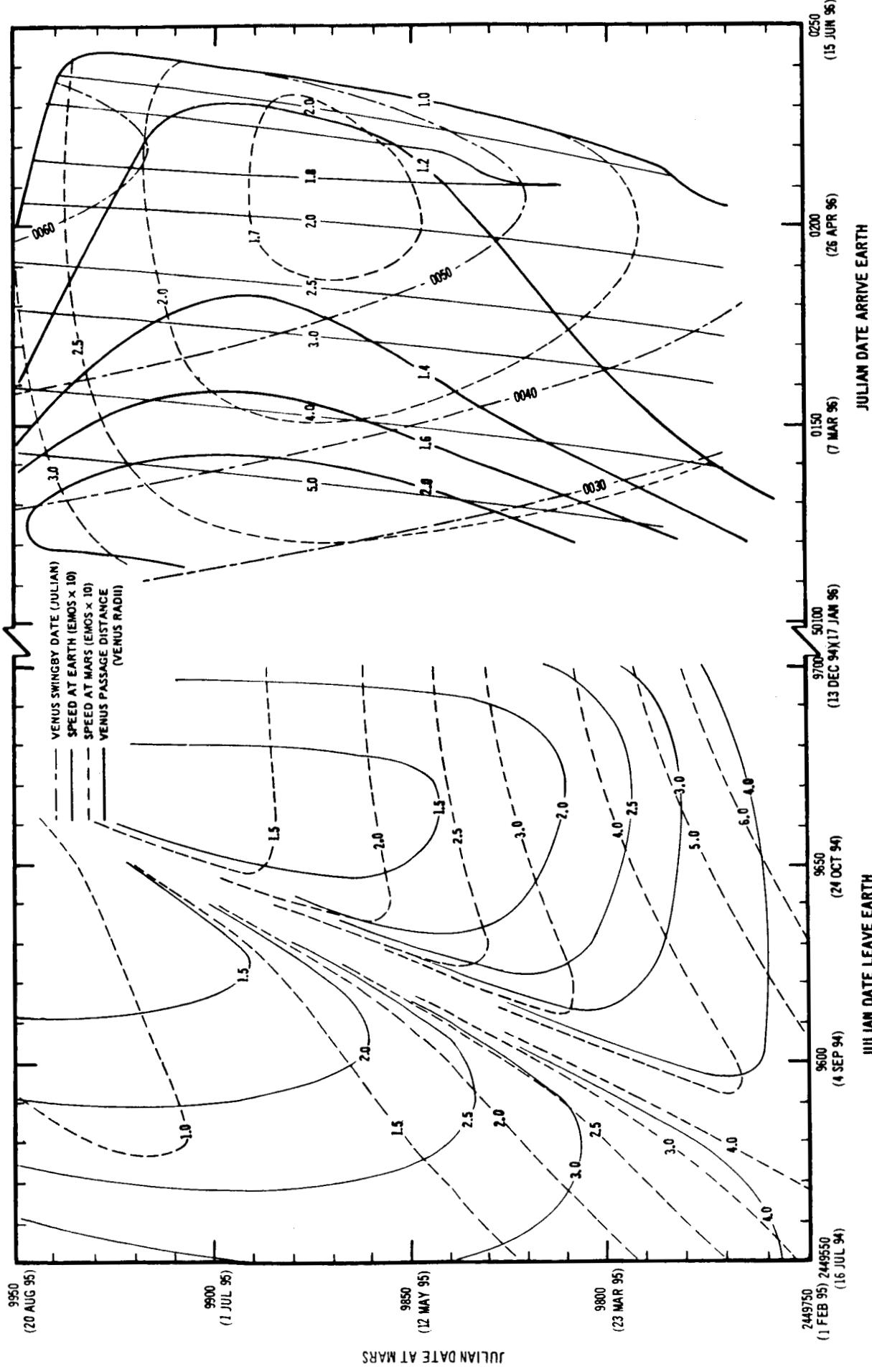


FIGURE 3-13A. 1995 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

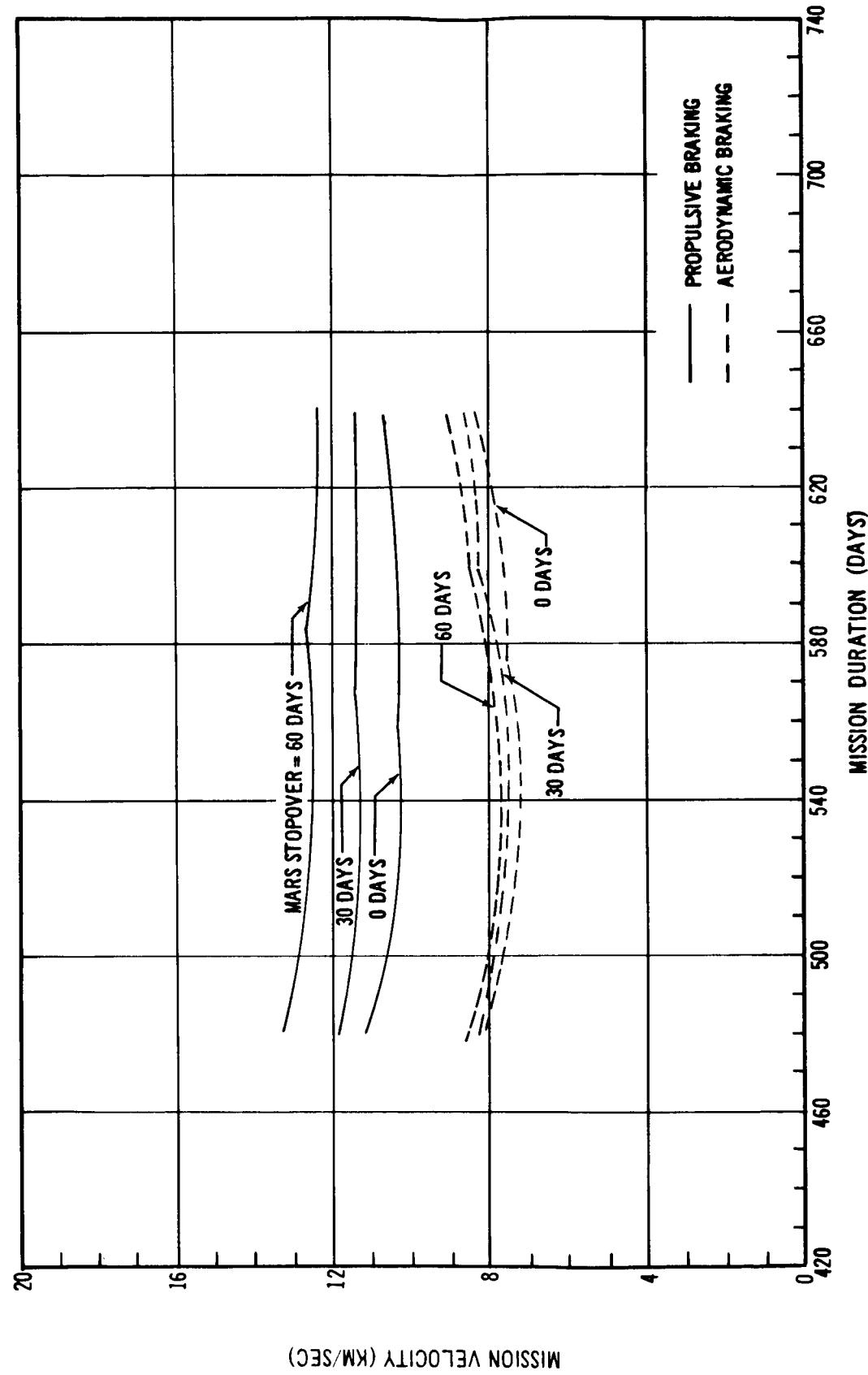


FIGURE 3-13B. 1995 INBOUND SWINGBY- MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

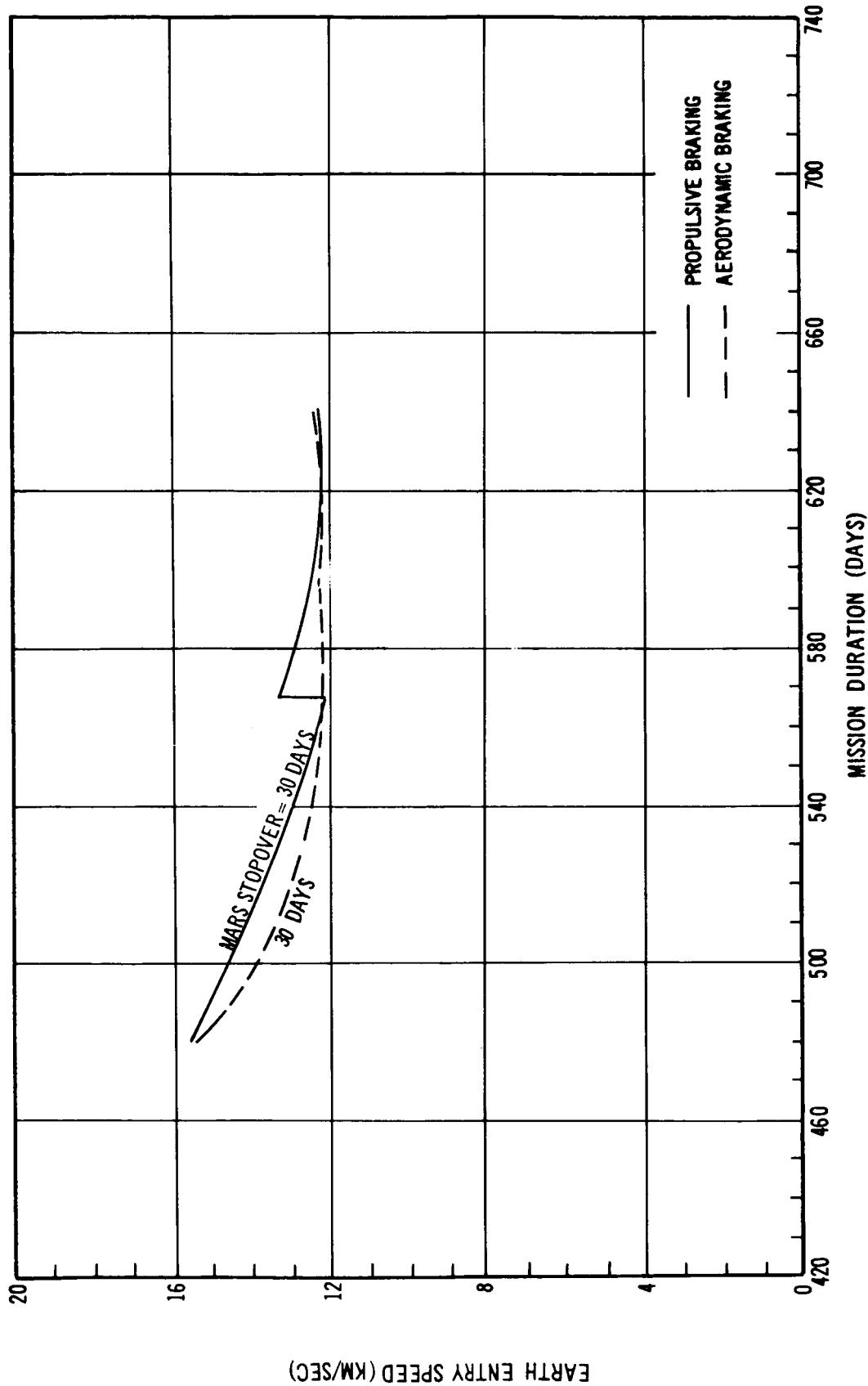


FIGURE 3-13C. 1995 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1997 OUTBOUND SWINGBY

The Category 5 opportunity shown employs a Type 2 trajectory from Earth to Venus and a Type 1 trajectory from Venus to Mars. Another family of missions with a Type 2/1 combination is available with Earth launch dates preceding 245 0100. There are also two families of missions with a Type 1/2 combination. The contour chart for one of these would overlay the family shown, and the other is available at Earth launch dates past 245 0200. Finally, in the same Mars arrival date range, there is a family with a Type 1/1 combination with Earth launch dates of 245 0240 and above.

Nearly all of the minimum velocities for the selected family in this opportunity are affected by the Venus passage distance constraint. The only missions that appear to yield stationary minima are:

	Stopover Time	Mission Duration
Propulsive Braking	{ 0	520, 560
	30	560, 600
	60	560, 600, 640
Aero Braking	{ 0	640
	30	640

The 640-day duration missions using propulsive braking at Mars employ direct return legs with Earth return dates on the boundary of the range investigated for all three stopover times. The same is true for aero braking except for the zero-day stopover case.

Unlike most other opportunities, the variation in the Earth entry speeds with stopover time for the family shown is sufficiently large that the entry speeds for all three stopover times are presented in part C of the figure.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

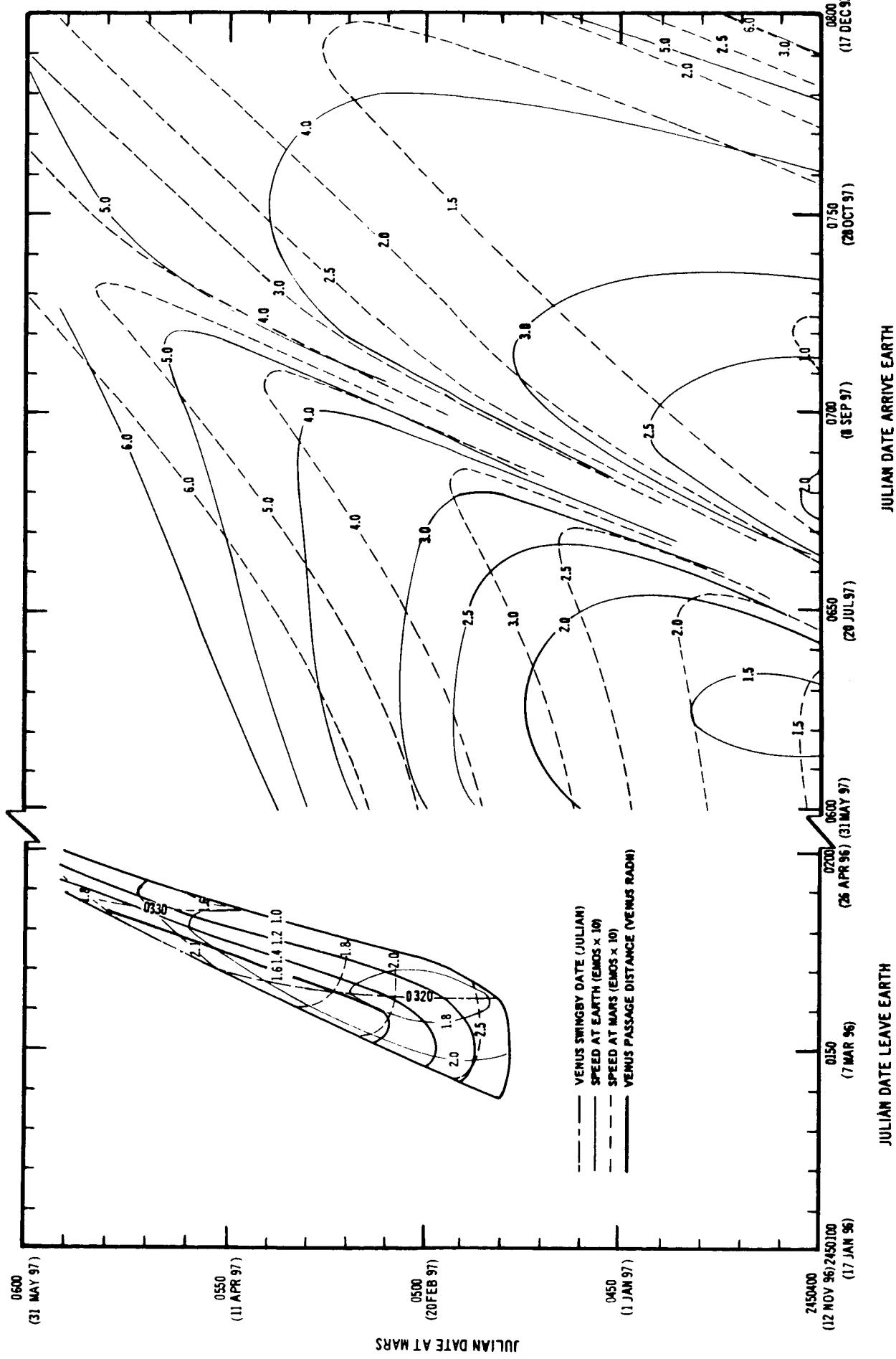


FIGURE 3-14A. 1997 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

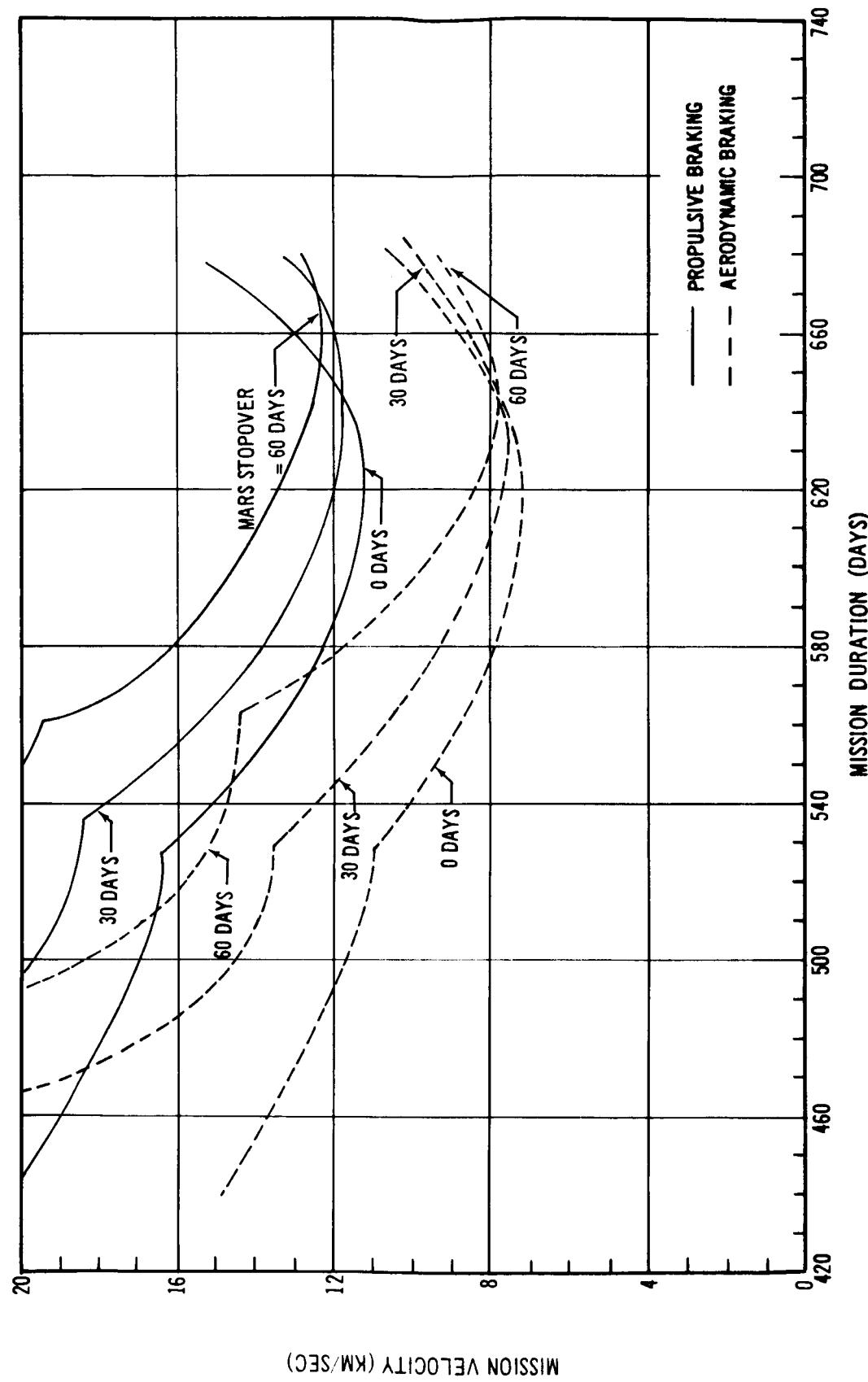


FIGURE 3-14B. 1997 OUTBOUND SWINGBY- MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

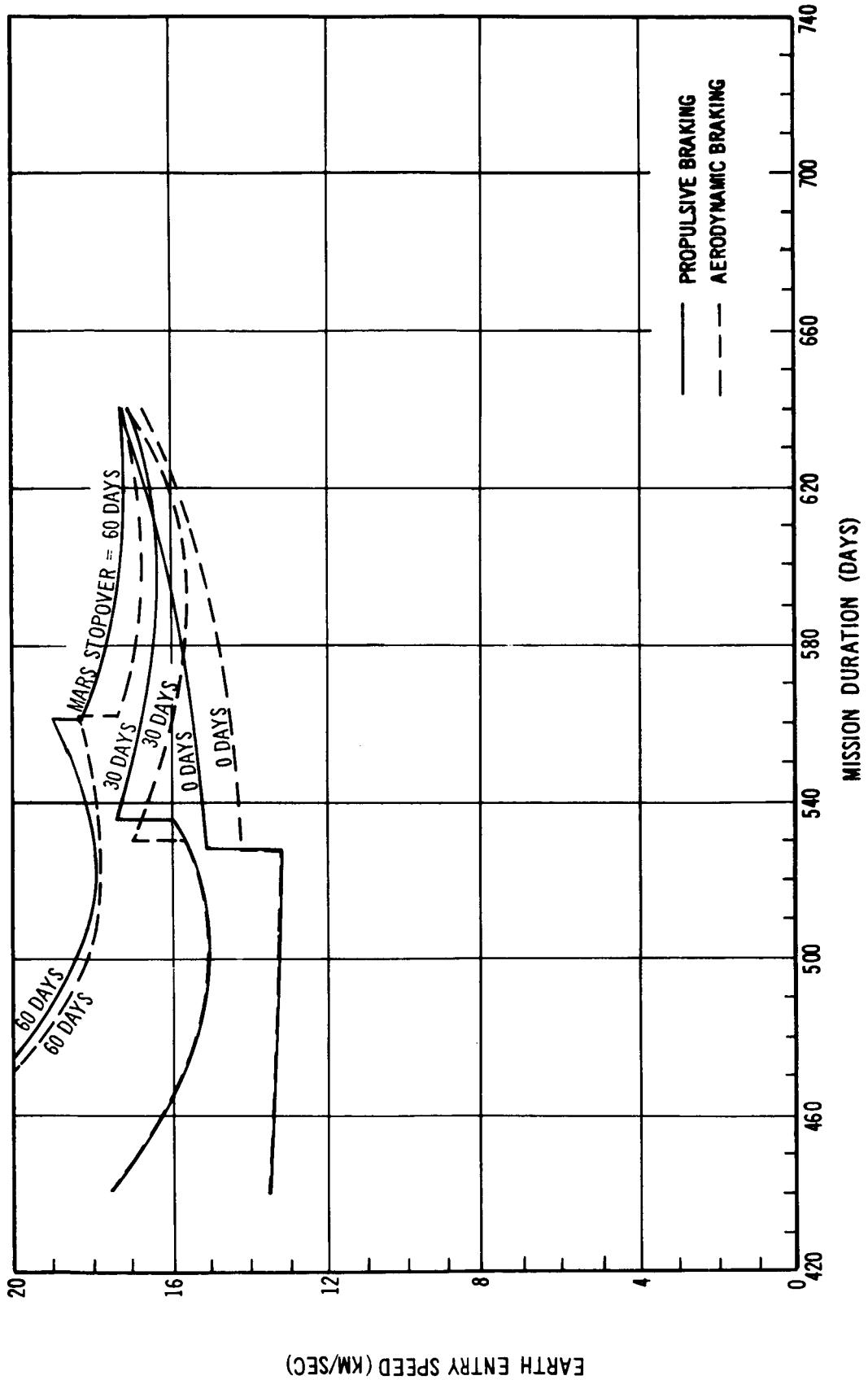


FIGURE 3-14C. 1997 OUTBOUND SWINGBY- EARTH ENTRY SPEEDS

1997 INBOUND SWINGBY

In this Category 5 opportunity, the swingby leg consists of a Type 1 trajectory from Mars to Venus and a Type 2 trajectory from Venus to Earth. There is also another family with a Type 1/2 combination in this opportunity that is not shown. This second family is characterized by Earth arrival dates around 245 0970. In addition, there is a family with a Type 2/1 combination, in approximately the same region as the family shown, and a family with a Type 1/1 combination with Earth arrival dates around 245 0800. All families have approximately the same Mars departure date range.

Most of the minimum velocity missions that yield the mission velocity chart lie on or near the 1.1 Venus radii passage distance constraint or they lie near the right edge of the window where the surface starts to fold back on itself. The few cases where the minima are stationary are:

	Stopover Time	Mission Duration
Propulsive Braking	{ 0	600
	30	640
Aero Braking	{ 0	480, 520, 560, 600
	30	560, 600, 640
	60	640

The Earth entry speeds associated with the minimum velocity missions are almost exactly the same for all three stopover times considered.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

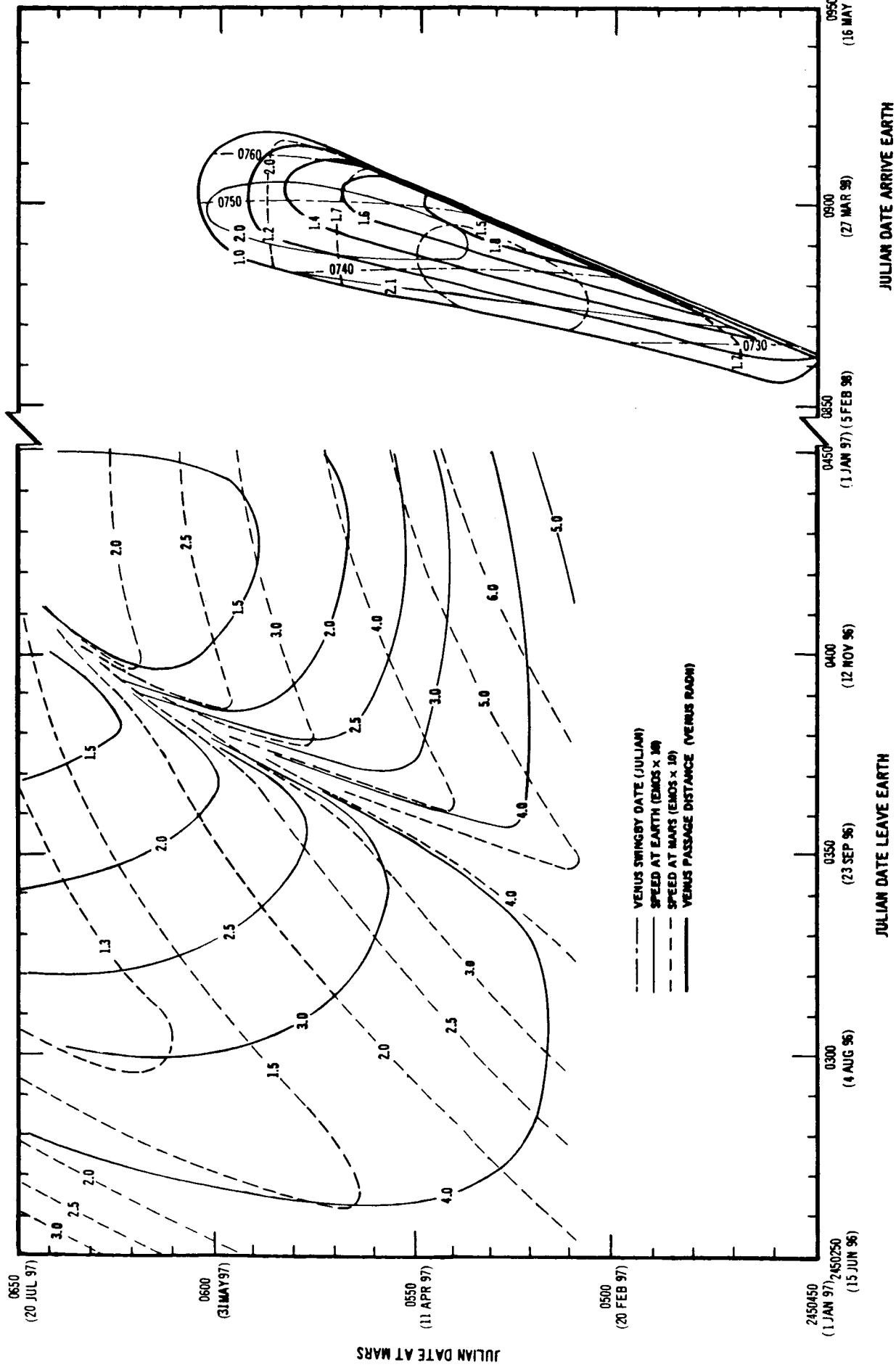


FIGURE 3-15A. 1997 INBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

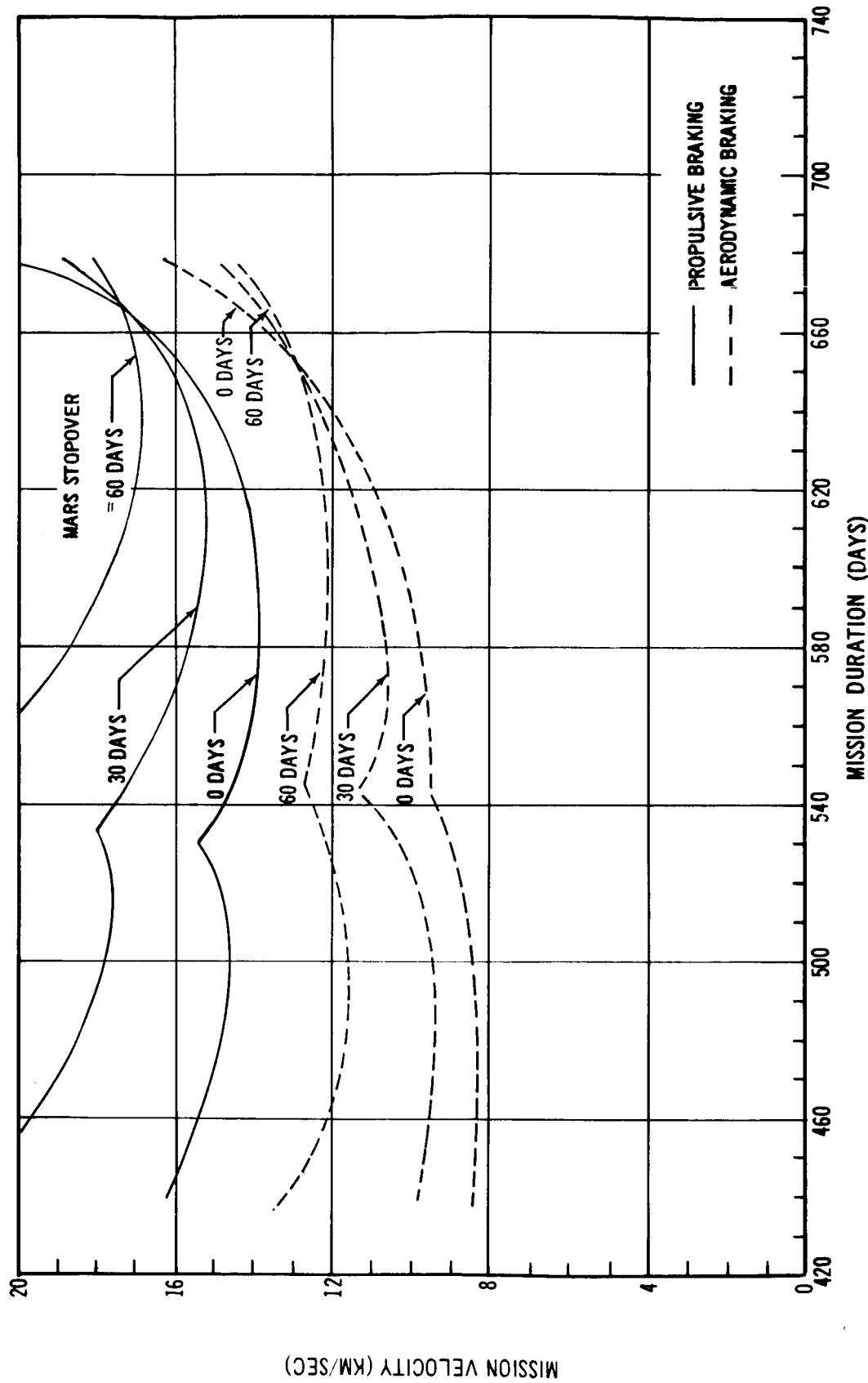


FIGURE 3-15B. 1997 INBOUND SWINGBY - MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

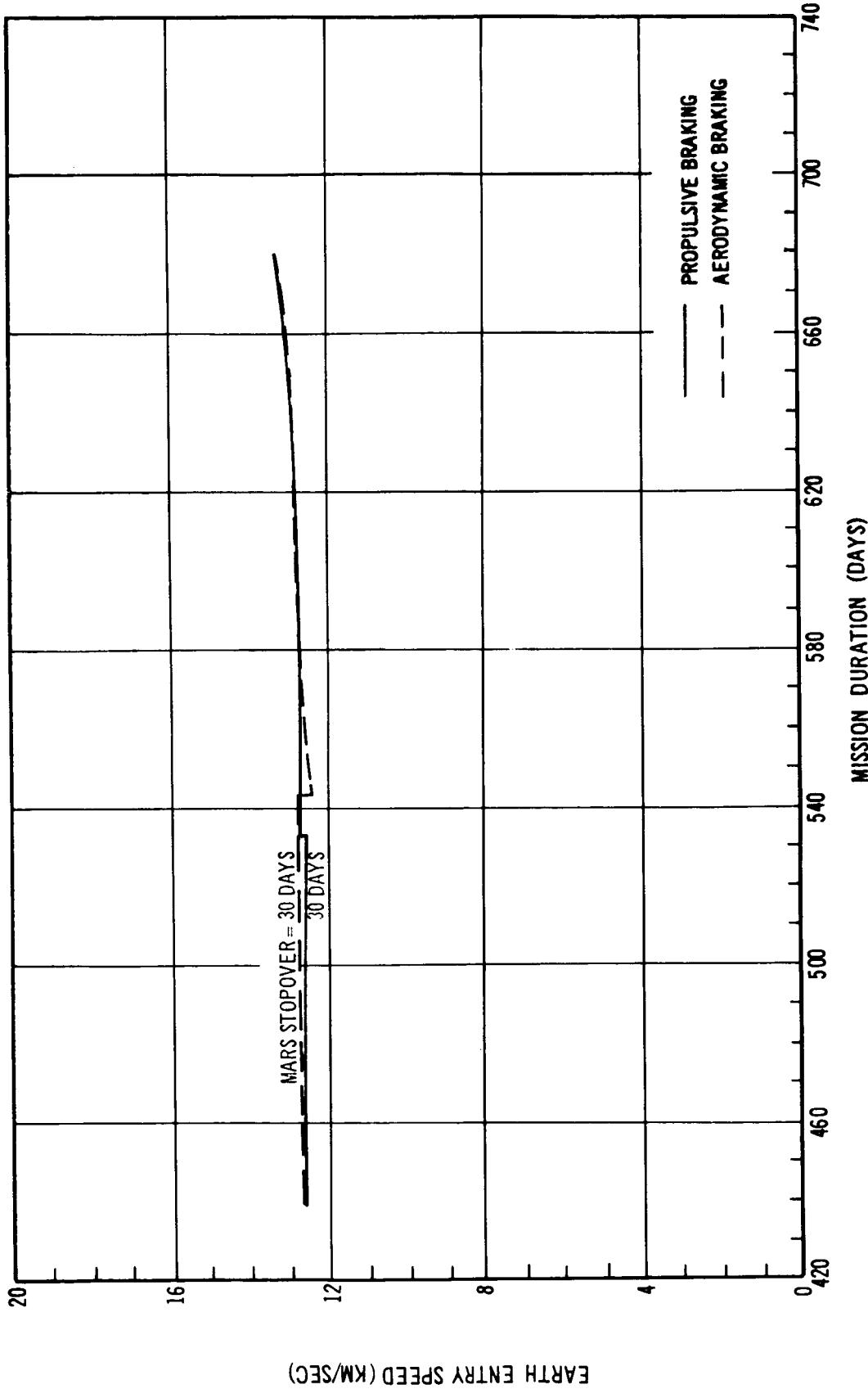


FIGURE 3-15C. 1997 INBOUND SWINGBY - EARTH ENTRY SPEEDS

1999 OUTBOUND SWINGBY

This Category 3 opportunity contains Type 2 Earth-to-Venus trajectories and Type 1 Venus-to-Mars trajectories. This is the only family available in the date ranges investigated. The most unusual feature in this family is the cut-out in the upper left corner of the swingby leg contours. A similar situation may be noted in the 1988 inbound opportunity. Physically, this is because the excess speed at Venus arrival is less than the minimum departure velocity requirement for a Venus-Mars trajectory.

For the most part the minimum mission velocities for propulsive braking at Mars are not affected by the constraint on Venus passage distance. The only exception is the 480-day mission duration, 60-day stopover case. On the other hand most of the minimum velocity missions for aerodynamic braking do lie on or very near the constraint. Those cases that appear to be exceptions are:

Stopover Times	Mission Durations
0	680, 720
30	680, 720
60	720

The 720-day duration, minimum velocity missions employ direct return trajectories with an Earth arrival date on the boundary of the date range investigated.

The Earth entry speeds associated with the minimum velocity missions for the zero and 60-day stopovers are generally within 1 km/sec or less of those for the 30-day stopovers.

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

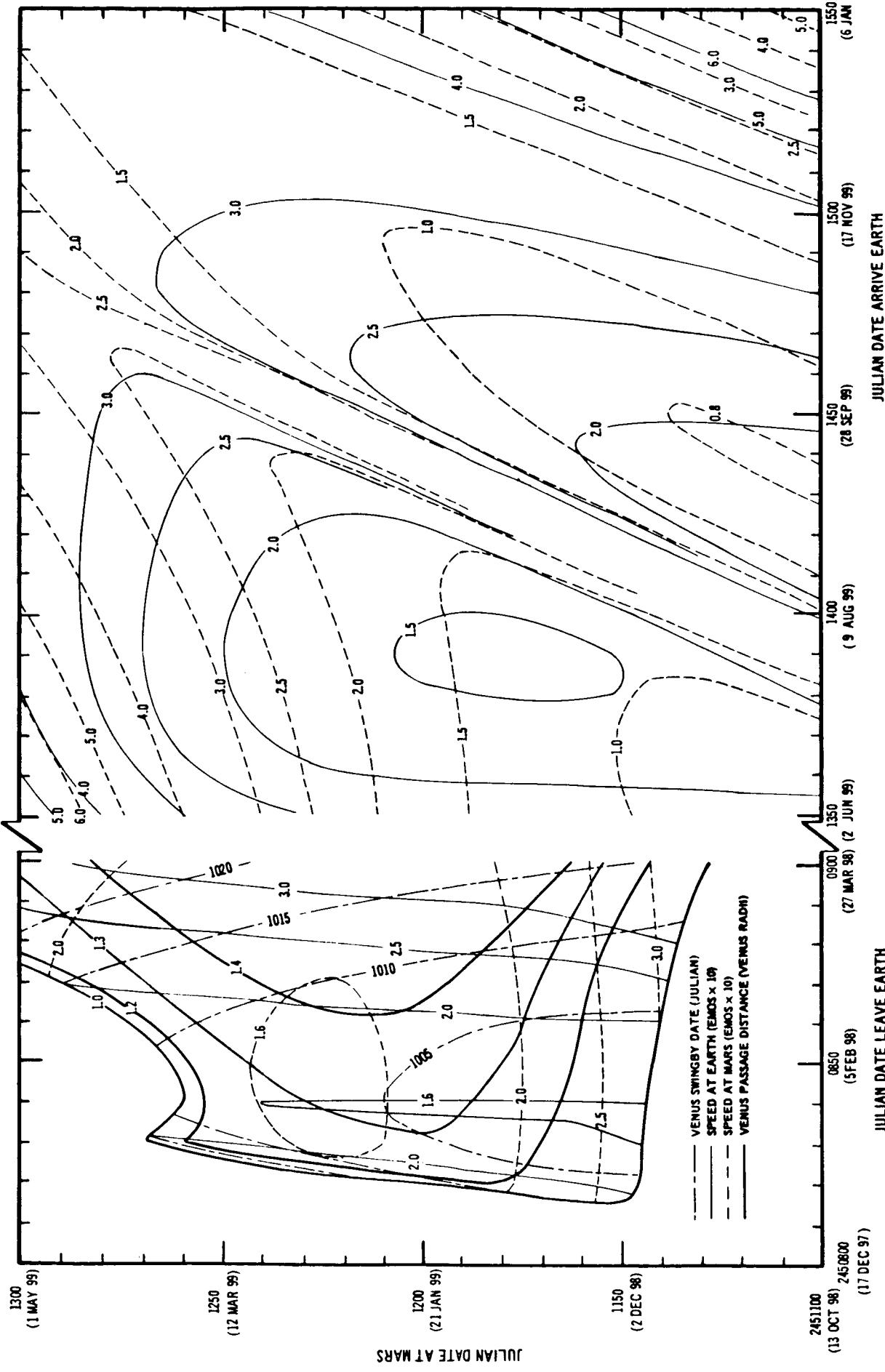


FIGURE 3-16A. 1999 OUTBOUND SWINGBY - CONTOUR CHART

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

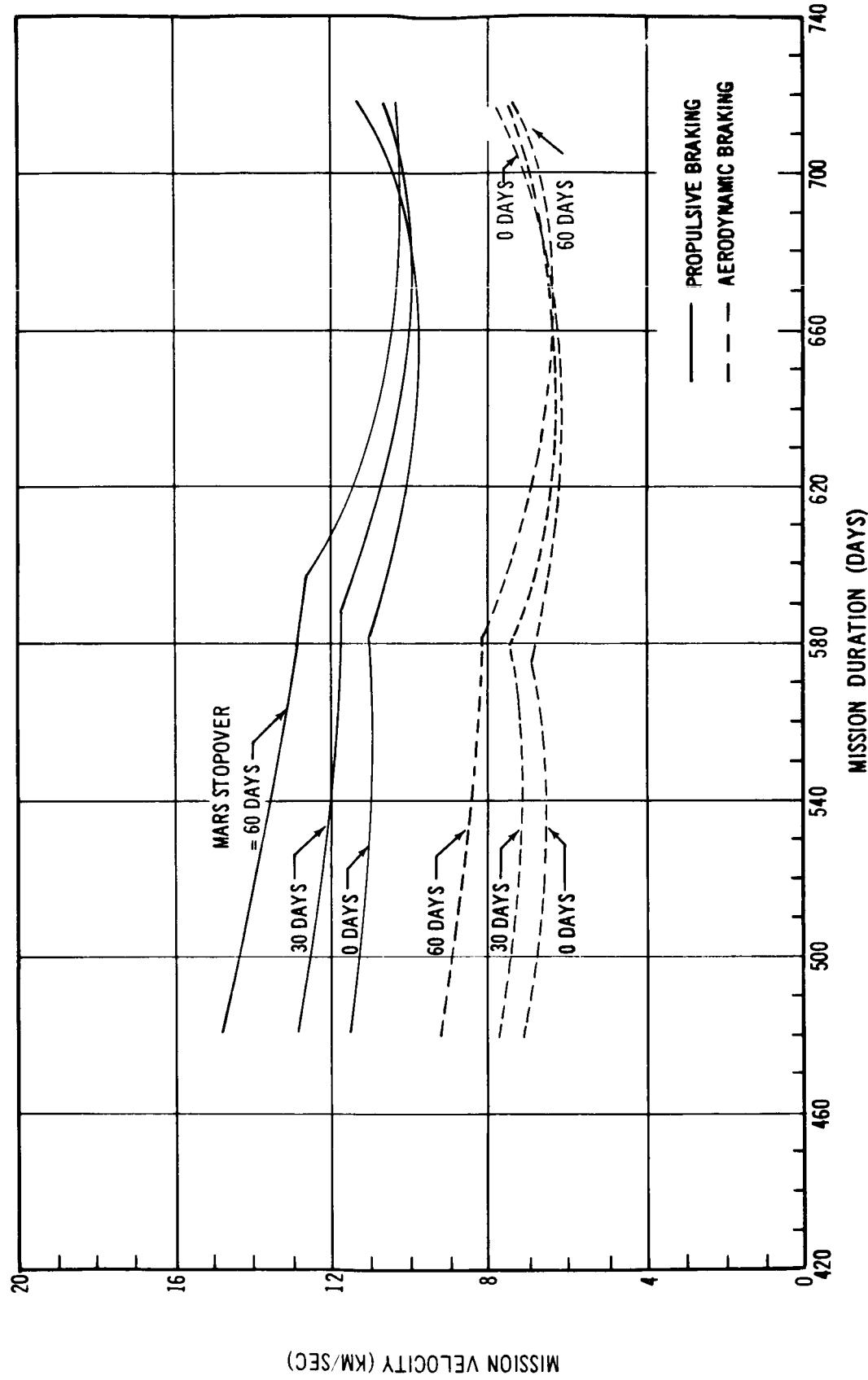


FIGURE 3-16B. 1999 OUTBOUND SWINGBY- MISSION VELOCITY REQUIREMENTS

MARS STOPOVER MISSIONS USING VENUS SWINGBYS

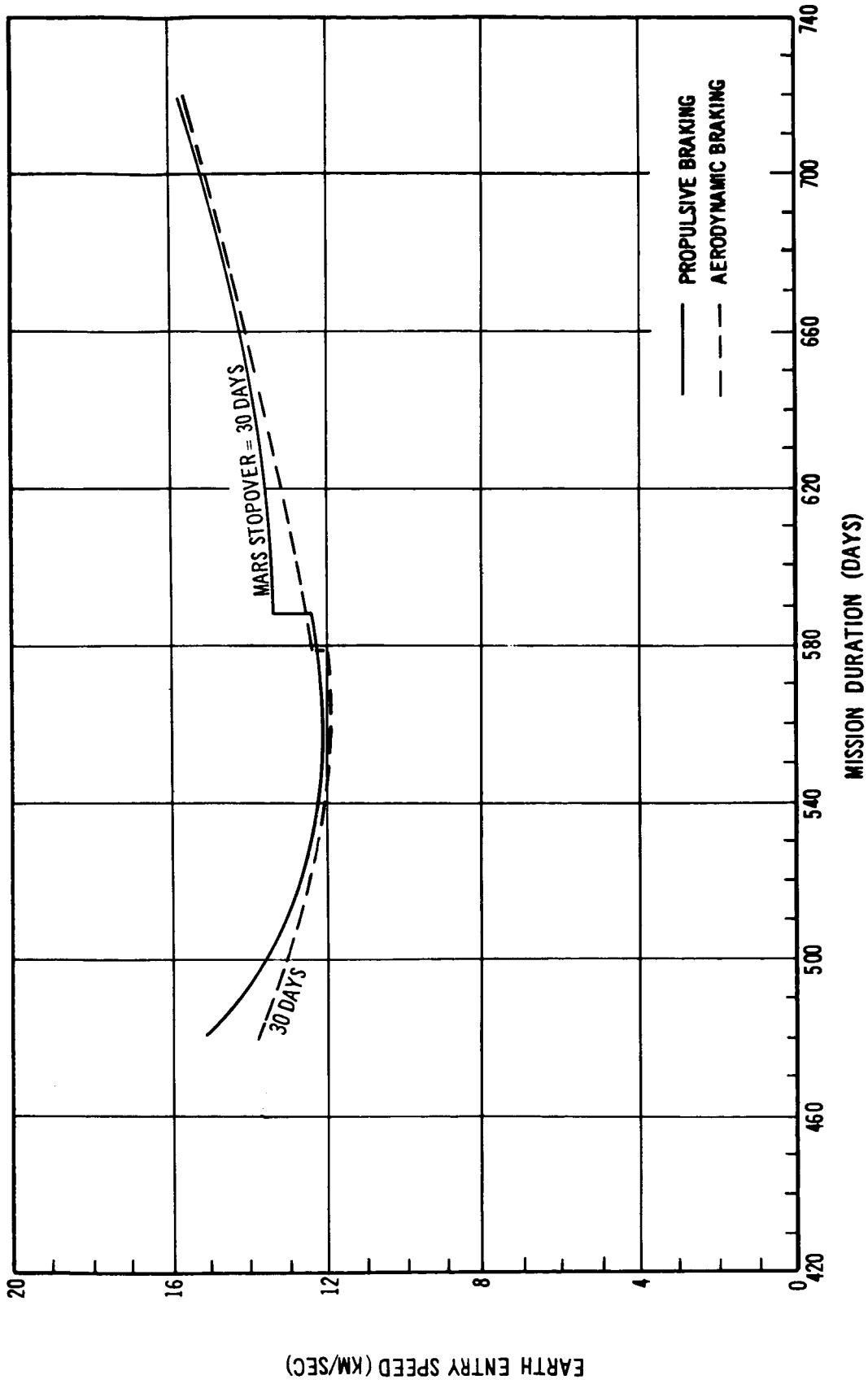


FIGURE 3-16C. 1999 OUTBOUND SWINGBY - EARTH ENTRY SPEEDS

Appendix
MAGNETIC TAPE DATA DESCRIPTION

The magnetic tape consists of separate data records for each swingby or direct trajectory. These data records are grouped into data blocks with each leg of each opportunity being one block. Within each block the data are presented chronologically and are organized by holding arrival date for the leg constant while varying the launch date. Multiple solutions occasionally occur for swingby trajectories where the Mars and Earth dates are the same but each solution has a distinct Venus swingby date. When this occurs, the data are arranged in order of increasing swingby date.

The data for each trajectory consist basically of the same quantities defined in Sections 4, 5 and 6 for the tabular data. In Table A-1 at the end of this appendix, is listed the symbol for each word in the data record. Except for the definitions given below, the symbols are as defined in Sections 4, 5, and 6. Note, however, that the event number on the symbols refer to the leg only and not to an entire mission. Thus, event No. 4 for swingby trajectories is arrival at the planet indicated by data word No. 3, NP_a, regardless of whether the mission is an inbound or outbound swingby. Note also that the SUN A represents the sun angle at the target planet whether it be Earth or Mars. The data are real numbers for all parameters except those specifically defined below as integers. No alphanumeric or BCD information is written on the tape.

For swingby trajectories, the record consists of 53 words while, for direct trajectories, 26 word records are used; words 27 to 53 contain data pertinent only to the second leg of swingby trajectories and to the actual swingby.

<u>SYMBOL</u>	<u>DESCRIPTION</u>
NP _d	Departure planet number, integer 4 for Earth or integer 5 for Mars.
NP _s	Swingby planet number, integer 3 for Venus or integer zero for direct legs.
NP _a	Arrival planet number, integer 4 for Earth or integer 5 for Mars.
JD _d	Julian Date (Minus 240 0000.0) at departure.
JD _s	Julian Date (Minus 240 0000.0) at Venus swingby. Zero for direct legs.
JD _a	Julian Date (Minus 240 0000.0) at arrival.
FLAG1	Type/Class flags for the first leg and second leg.*
FLAG2	These are five digit integers containing the type and four class flags for each leg. The five digits can be represented as

1C ₁	1C ₂	T	2C ₁	2C ₂
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where:

T is the type flag with

T = 1 for Type 1 ($0^\circ \leq \phi < 180^\circ$), and

T = 2 for Type 2 ($180^\circ \leq \phi < 360^\circ$),

where ϕ is the transfer angle,

and:

v_D^C is a class flag which is 1 or 2 according to whether a particular hyperbolic excess velocity (v_{∞}) decreases or increases with an increase in flight time (t_f) while holding a particular date (T_D) fixed. This can be stated in terms of partial derivatives as

*These flags are useful in distinguishing among the various families within a given opportunity.

$$v_D^C = 1 \text{ when } \left. \frac{\partial V_{\infty v}}{\partial t_f} \right|_{T_D} < 0 ,$$

and:

$$v_D^C = 2 \text{ when } \left. \frac{\partial V_{\infty v}}{\partial t_f} \right|_{T_D} > 0 ,$$

where:

$$\begin{aligned} V_{\infty v} &= V_{\infty} \text{ at departure for } v = 1 \\ &= V_{\infty} \text{ at arrival for } v = 2 , \end{aligned}$$

and:

$$\begin{aligned} T_D &= \text{date at departure for } D = 1 \\ &= \text{date at arrival for } D = 2 . \end{aligned}$$

Since v_D^C is calculated by finite differences, the class flags may not always be correct in regions where the corresponding partials go to zero. ${}_1 C_2$ and ${}_2 C_2$ are set to zero for direct legs because they were not calculated.

The data blocks mentioned above are each headed by an ID record which serves both to define certain parameters pertinent to the block and to separate the blocks from each other. To facilitate reading, the ID record consists of 53 words of which only the first four contain data, the rest being zero. Below is a description of each word in the ID record.

<u>WORD</u>	<u>DESCRIPTION</u>
1	An integer flag set to 1000 to distinguish this record from the data records which contain the launch planet number in the first word.
2	The integer calendar year of the mission opportunity represented by the data block.

3

An integer flag indicating the leg represented by the block.

= +2 for outbound swingby
= -2 for inbound swingby
= +1 for outbound direct
= -1 for inbound direct

4

The integer number of words on each data record in the block = 53 for swingby data and = 26 for direct data.

5 - 53

Not used, set to zero.

The data blocks are arranged first by the leg and then by the opportunity. Below is a list of the blocks in the order in which they are to be found on the tape.

<u>BLOCK</u>	<u>DESCRIPTION</u>
Outbound Swingbys	
1	1978
2	1980
3	1984
4	1986
5	1990
6	1993
7	1997
8	1999
Inbound Swingbys	
9	1975
10	1978
11	1982
12	1984
13	1988
14	1990
15	1995
16	1997

Outbound Direct

17	1975
18	1978
19	1982
20	1984
21	1988
22	1990
23	1995
24	1997

Inbound Direct

25	1978
26	1980
27	1984
28	1986
29	1990
30	1993
31	1997
32	1999

At the end of the last block is an ID record with a zero in the second word to signal the end of the tape. All of the trajectory data are written on one file.

The data are stored on the magnetic tape at a density of 800 bits per inch. The tape itself was prepared for reading by an IBM 7094 Fortran IV Version 12 or Version 13 system. The entries contained on the tape were limited to binary numerical data to facilitate conversion of the tape to other systems.

TABLE A-1
WORD STORAGE MAP

DATA WORD	SYMBOL	DATA WORD	SYMBOL
1	NP _d	27	SPEED3
2	NP _s	28	RA3
3	NP _a	29	DECL3
4	JD _d	30	I 3
5	JD _s	31	V 3
6	JD _a	32	PSI 3
7	SUN A	33	ECCEN
8	SPEED1	34	SMA
9	RA1	35	THET3
10	DECL1	36	THET4
11	I 1	37	PERIH
12	V 1	38	APHEL
13	PSI 1	39	PSI 4
14	ECCEN	40	V 4
15	SMA	41	I 4
16	THET1	42	DECL4
17	THET2	43	RA4
18	PERIH	44	SPEED4
19	APHEL	45	FLAG2
20	PSI 2	46	KAPPA
21	V 2	47	-A
22	I 2	48	E
23	DECL2	49	INC
24	RA2	50	RAP
25	SPEED2	51	DECLP
26	FLAG1	52	ETA
		53	PERIC

REFERENCES

1. Sohn, R. L., "Venus Swingby Mode for Manned Mars Missions," Journal of Spacecraft and Rockets, Vol. 1, No. 5, September - October 1964.
2. Hollister, W. M., The Mission for a Manned Expedition to Mars, ScD. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1963.
3. Deerwester, J. M., "Initial Mass Savings Associated With the Venus Swingby Mode of Mars Round Trips," AIAA 2nd Aerospace Sciences Meeting, Paper No. 65-89, January 1965.
4. Gillespie, R. W. and S. E. Ross, "The Venus Swingby Mission Mode and Its Role in the Manned Exploration of Mars," Journal of Spacecraft and Rockets, Vol. 4, No. 2, February 1967.
5. Deerwester, J. M., and S. M. D'Haem, "Systematic Comparison of Venus Swingby Mode With Standard Mode of Mars Round Trips," Journal of Spacecraft and Rockets, Vol. 4, No. 7, July 1967.
6. Space Flight Handbooks, Vol. 3 - Planetary Flight Handbook, NASA SP-35, Part 1, Prepared for the George C. Marshall Space Flight Center, 1963.
7. Nautical Almanac Offices of the United Kingdom and the United States of America, Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac, London, Her Majesty's Stationery Office, 1961.
8. Clarke, V. C., Jr., Constants and Related Data for Use in Trajectory Calculations, JPL Technical Report No. 32-604, March 1964.
9. Makemson, M. W., R. M. L. Baker, Jr., and G. B. Westrom, Analysis and Standardization of Astrodynamical Constants, University of California Technical Report No. 12, February 1961.
10. VanderVeen, A. A., "Venus Swingbys for Manned Mars Missions During the 1978 - 1986 Time Period," AAS Space Flight Mechanics Specialist Conference, Paper No. 66-125, July 1966.

